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HON. J. ANGUS MACLEAN, M.P.,
Minister of Fisheries

An Assessment of Jones Creek Spawning Channel 1954-1961

by

D. MacKinnon, L. Edgeworth and R. E. McLaren*

Department of Fisheries of Canada, Vancouver, B.C.

EDITOR'S NOTE: The 1961 Jones Creek pink salmon run totalled slightly more than 5000 adults. Of these 4388 spawned in the channel above the counting fence and approximately 700 spawned below the channel. The deposition in the channel is estimated at 3,789,300 eggs, based on the count of the 2229 females that entered the channel.

Abstract

A detailed description of the Jones Creek spawning channel is provided along with an assessment of its operation, maintenance and results during the seven years following construction. Operational costs of the channel have been low and pink salmon egg-to-fry survivals relatively high. Significant increases in numbers of each generation of adult salmon have been recorded.

Introduction

The Jones Creek Spawning Channel was constructed in 1954 as a solution to salmon problems created by a high-head diversion-type hydroelectric development at Jones (Wahleach) Lake 10 miles southwest of Hope, B.C. The B. C. Electric Company constructed a dam at the outlet of Jones Lake, diverting the outflow through a tunnel to the powerhouse located at a site adjacent to the Fraser River eight miles downstream from the mouth of Jones Creek (Fig. 1). This diversion substantially reduced the supply of water in the lower reaches of Jones Creek where a well-established run in the order of 6000 pink salmon (*Oncorhynchus gorbuscha*) spawned every odd-numbered year and smaller numbers of chum salmon (*O. keta*) and coho salmon (*O. kisutch*) spawned each year.

The channel, the first of several artificial spawning channels constructed for the propagation of Pacific salmon, now has a history of seven years of operation, maintenance and biological results. With the obvious interest in this type of facility as a possible solution to problems created by hydroelectric development, along with its potential value in developing and rehabilitating salmon runs, it is considered important at this time to assess the operation, maintenance and biological results of this channel.

The construction of the channel and initial operation in 1954 has been described in a previous report (Hourston & MacKinnon, 1956). It is considered necessary, however, for purposes of the ensuing discussion, to review certain pertinent details on the development, design and construction of the channel.

Surveys and studies were initiated in 1949 by engineers and biologists of the Fish Culture Development Branch of the Canada Department of Fisheries, which resulted in an agreement that the company would construct and maintain an artificial

* Presented at the Tenth Pacific Science Congress of the Pacific Science Association, held at the University of Hawaii, Honolulu, Hawaii, U.S.A., August 21 to September 6, 1961.

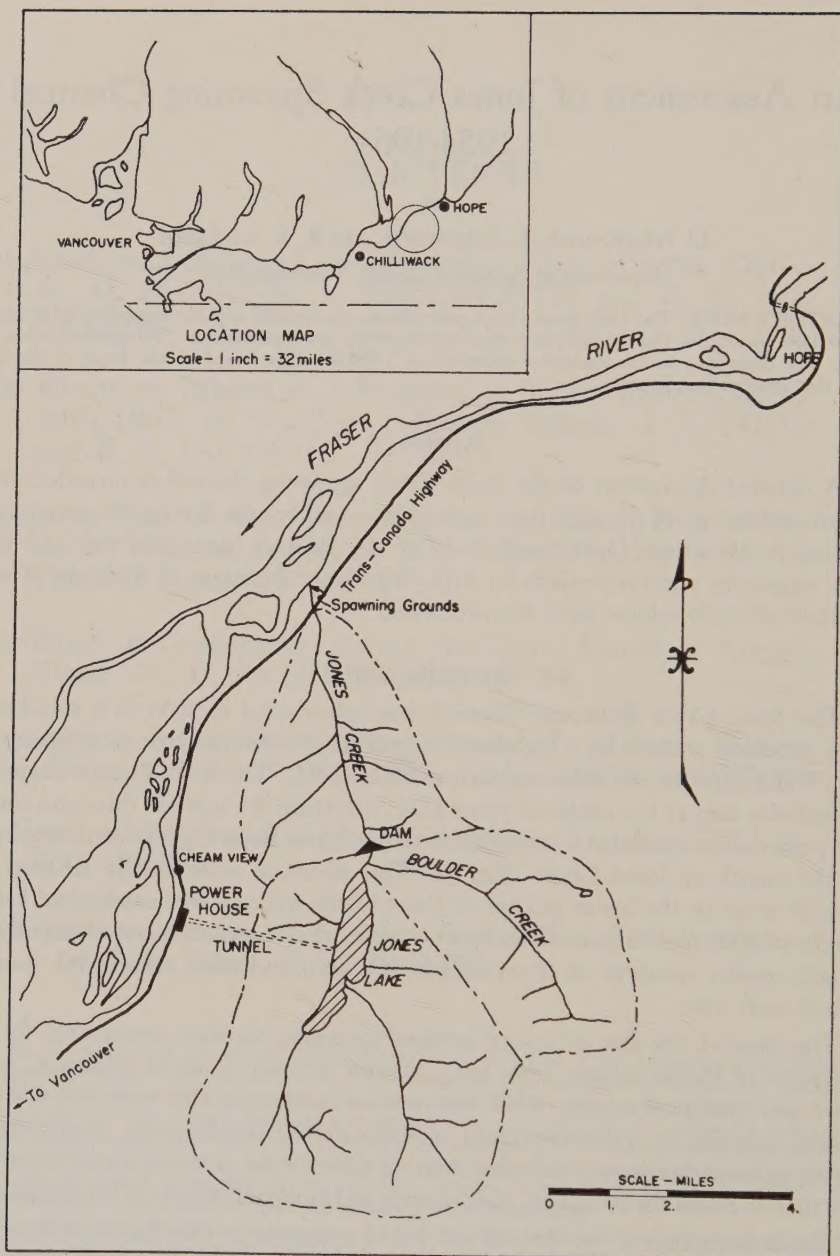


FIGURE 1. Location map and hydro-electric power development plan of the Jones Lake System.

spawning channel alongside the stream bed of Jones Creek. The specifications for the channel which were provided to the company were based on the premise that the total spawning area, gravel size, gradient and velocities in the spawning stream would be duplicated in the artificial spawning channel. The flows specified were of sufficient magnitude to accommodate the total run of pink salmon in the channel without seriously affecting the economy of the power project.

Description of Spawning Channel

The natural spawning area available in Jones Creek prior to the power development was approximately 2200 square yards which supported a maximum run of 6300 pink salmon and a few hundred chum and coho salmon. The channel was designed to provide an equivalent spawning area which allowed an average of 0.70 square yards per female pink salmon.

In order to provide an adequate flow for proper operation of the spawning channel the residual flow from the drainage area below the dam is augmented by spilling water from an outlet works constructed in Boulder Creek, a major tributary stream which flows into the reservoir near the dam, (Fig. 1).

The artificial channel diagrammatically shown in Fig. 2 is approximately 2000 feet in length and ten feet wide at the bottom with side slopes of $1\frac{1}{2}$:1. The channel was designed for a water depth range of from one to two feet and for a velocity range of from one to two and one-half feet per second. Baffles made of two 4" $\times$ 6" timbers were installed to control the depth and velocity at 100-foot intervals except at the channel entrance where six baffles were installed at 15-foot intervals. Baffles were necessary to localize excess drop in the channel. The drop per baffle was set at a maximum of one foot but varies between four and 12 inches depending on topographic and other considerations.

The intake to the channel is a reinforced concrete box with a 42-inch diameter Calco regulating gate connected to 70 feet of 42-inch diameter 12-gauge corrugated pipe. A low concrete weir was constructed downstream of the intake box in the original stream bed, which is now the flood channel. The intake works was designed to pass up to 50 cfs into the channel and to bypass flows in excess of the spawning channel requirements. The average flow required for the operation of the channel is 20 cfs but this flow can be increased during adult migration and decreased during the incubation period.

Gravel ranging in size from $\frac{1}{4}$ " to $1\frac{1}{2}$ " was deposited in the channel to a depth of from 12 to 18 inches. The grading curve for this gravel is shown in Fig. 3. This figure also shows the grading limits that were prepared as a guide to the B. C. Electric in obtaining suitable spawning gravel. The limits were established by plotting grading curves of gravel samples from several spawning streams including Jones Creek. It was not intended that optimum size gravel be used as was the case for the Robertson Creek channel, where the gravel size varied from $\frac{3}{4}$ " to 4" (Lucas, 1960) but rather that the gravel have a grading curve equivalent to good natural spawning gravel. The gravel actually used in the channel was surplus gravel which had been screened for construction purposes, but since it was readily available and had a grading curve within the specified limits, it was approved for use in the channel.

A fish diversion structure, 230 feet long, was constructed across the original stream bed to prevent fish from entering the flood channel. Eighty feet of the structure is a barrier fence which is parallel to the channel entrance, and its location is such that fish are directed into the channel (Fig. 4). The balance of the structure is a low timber dam with an open spillway designed to pass flood flows. There is, however, no overflow during normal river discharge. Cross-sections of the barrier fence and spillway are shown in Fig. 5.

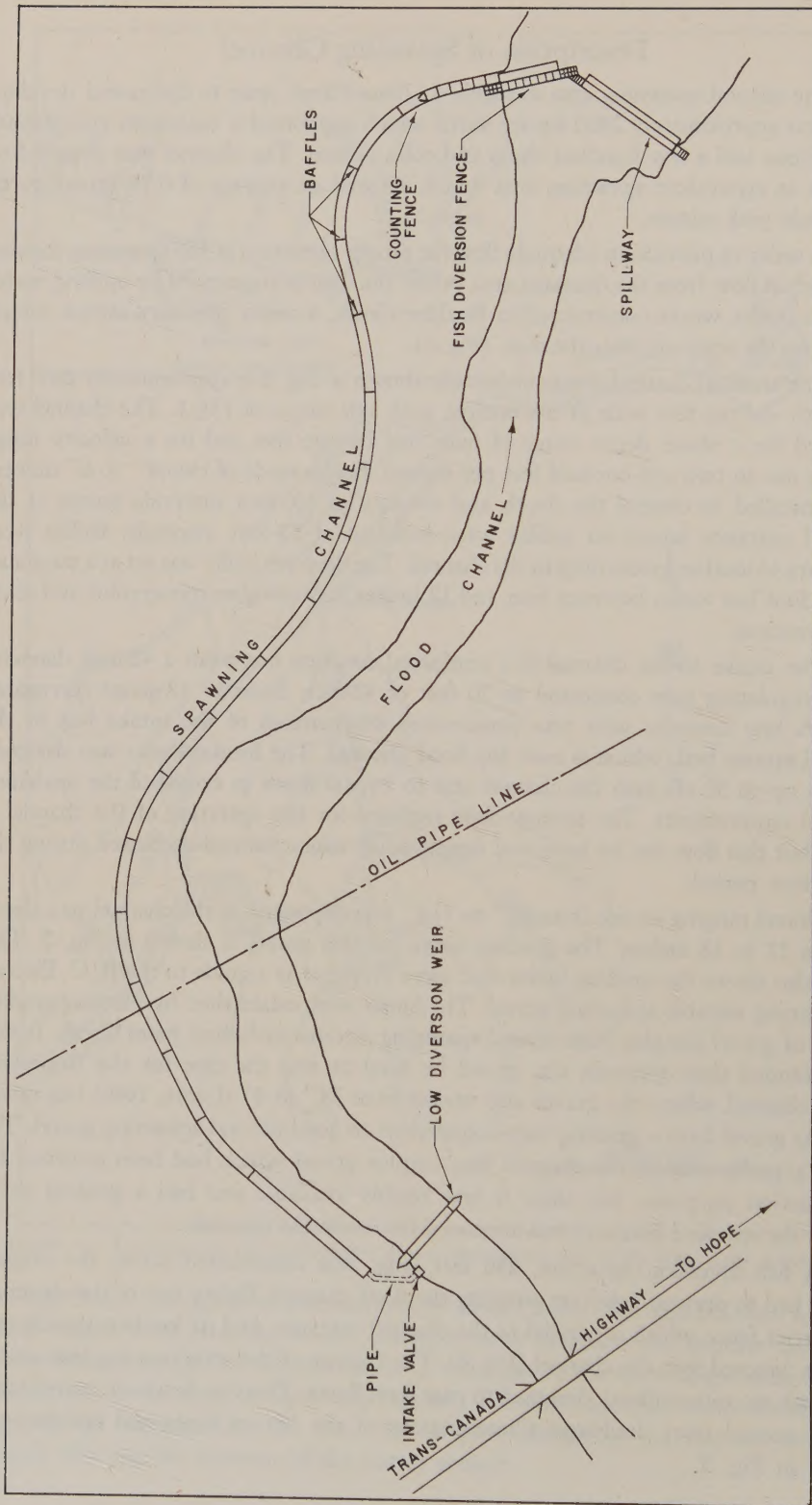


FIGURE 2. Spawning channel & appurtenant structures.

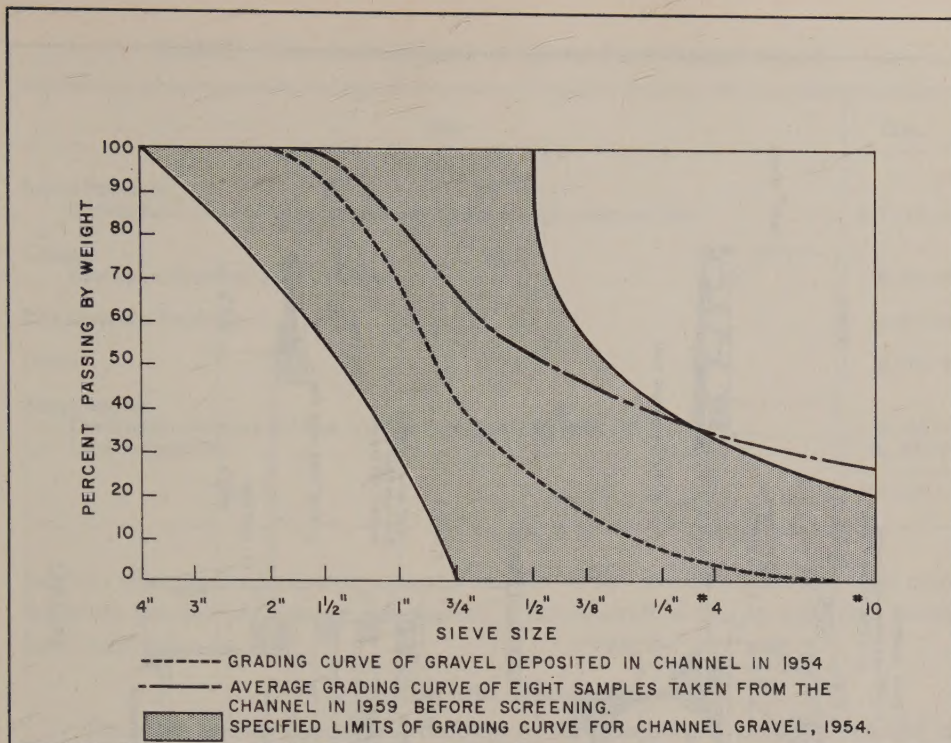


FIGURE 3. Graph showing specified limits of grading curve for gravel for spawning channel; grading curve for gravel actually deposited in 1954; and average grading curve of eight samples taken from channel in 1959 before screening.



FIGURE 4. The fish diversion fence and spawning channel entrance during a low flow period.

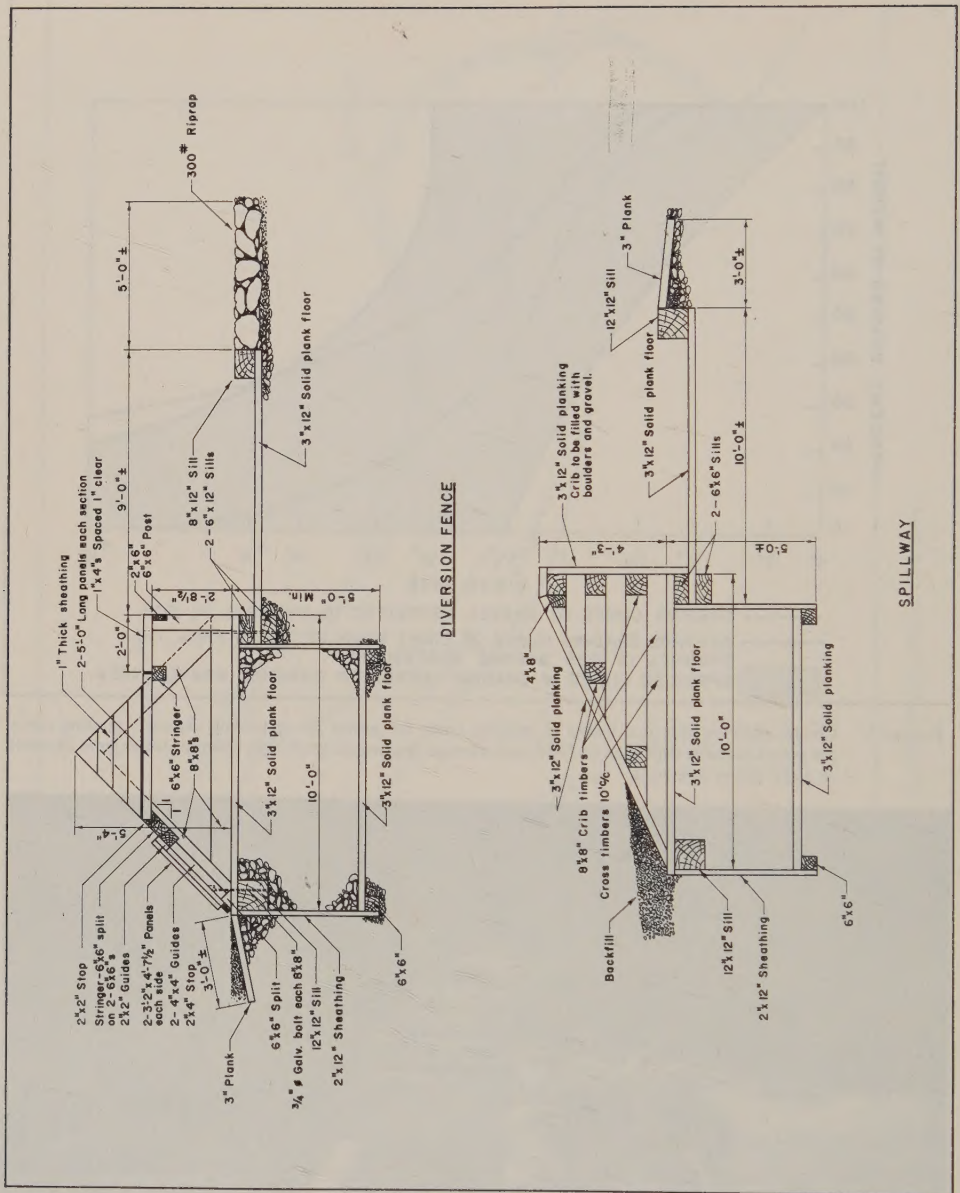


FIGURE 5. Cross-sections of fish diversion fence and spillway.

Table I shows the construction costs of the channel and appurtenant structures. It will be noted that 62 per cent of the total cost was expended for the purchase of property and for the construction of the fish diversion weir. The high property cost resulted from the fact there was only one possible site for the location of the channel owing to the topography of the area. The high cost of the fence resulted from its

Table I. Construction Costs of Channel and Appurtenances

Item	Cost
Intake Structure	
Settling basin, diversion weir, control gate structure, and corrugated pipe	\$ 5,000.00
Channel	
Clearing, excavating, gravel, baffles	6,500.00
Fish Diversion Structure	21,800.00
Dykes	3,000.00
Miscellaneous	
Contractors overhead and fees, legal surveys, gravel analysis, etc.	8,300.00
Land Acquisition	16,200.00
Total	\$60,800.00

location of necessity at a wide, unstable section of the creek. If there had been more flexibility possible in locating the channel, a considerable saving in total cost would have resulted.

Operation and Maintenance

The most serious operational problem of the channel has been the removal of deposited silt and sand from the channel. Most of this silt and coarser bed load material is deposited in the channel during heavy fall freshets. In two years out of the first five years of operation it was necessary to loosen and flush fine material from the channel by means of a small rubber-tired tractor with a rake blade. By 1959, the sixth year of operation, the fine material had built up to such an extent that it was necessary to remove, screen, and replace the gravel. The average grading curve for eight gravel samples taken at 200-foot intervals prior to the screening is shown in Fig. 3. All material finer than $\frac{1}{4}$ -inch was removed from the gravel.

The upper 100 feet of the channel is used as a basin for collecting the fine material. While this basin has been effective in collecting a large part of the silt and sand, a considerable amount is still deposited downstream in the channel. Consideration is being given to means such as a vortex tube of collecting and automatically ejecting as much as possible of the silt to the flood channel. Another possible method of reducing the volume of fine material entering the channel would be to flush the material which settles in the intake basin down the flood channel. This would entail constructing a sluice gate in the diversion weir adjacent to the intake pipe and excavating a larger intake basin.

Some difficulty has been encountered with icing conditions in the channel. During the winter of 1956-57 the channel was covered with 6-10 inches of ice. Small ice jams formed, which caused scouring of the gravel and erosion of the dykes. In one instance the channel dyke was breached, which resulted in considerable mortality to eggs in the gravel.

The lack of vegetation along the banks of the channel during the period immediately after construction was undesirable in two respects. Observations showed that

the adult salmon used all available cover and shade, especially during their pre-spawning period in the channel. In addition there was considerable evidence of bank erosion during the first two years of operation. These disadvantages are rapidly being rectified by the natural growth of vegetation. Comparison of Fig. 6 and Fig. 7 shows the change in bank vegetation in the seven-year history of the channel. No serious erosion has occurred since 1957 and adult salmon presently in the spawning channel are showing considerably fewer alarm reactions. In addition these fish appear to be more evenly distributed within each 100-foot section. Where in previous years the fish favored the periphery of the channel and the turbulent area below the baffles there is now a considerably larger percentage of fish in the mid-stream areas.



FIGURE 6. A section of the spawning channel showing the lack of vegetation on the banks in 1954.

The annual operating and maintenance costs of the channel during the period 1955-60 are shown in Table II.

It will be noted from Table II that apart from the removal of silt from the channel very little maintenance has been required. During the spawning and incubation period routine inspections of the channel are carried out once or twice a week. During adverse weather conditions more frequent inspections are undertaken.

One of the two 4" x 6" baffles at each drop structure is removed immediately after spawning has been completed which results in increased velocities and decreased depths throughout the channel. This procedure decreases the amount of sedimentation during the incubation period and reduces the amount of ice formation in the stilling pools below the baffles.



FIGURE 7. A section of spawning channel showing the increase of natural vegetation of the banks by 1961.

Table II. Operation and Maintenance Costs*—
Jones Creek Spawning Channel 1955-60

Year	Inspection	Silt Removal	Miscellaneous repairs and maintenance	Total
1954.....		Year of construction		
1955.....	\$ 250	\$ Nil	\$ Nil	\$ 250
1956.....	250	Nil	Nil	250
1957.....	250	2,500	2,310	5,060
1958.....	250	400	Nil	650
1959.....	250	3,790	Nil	4,040
1960.....	250	Nil	Nil	250
Total.....	\$1,500	\$6,690	\$2,310	\$10,500
Average.....	\$ 250	\$1,115	\$ 385	\$ 1,750

* Costs provided by B.C. Electric Company.

The costs shown in Table II are for the operation of the channel only and do not include any costs for maintaining an adequate water supply for the channel. For periods of approximately two weeks in September during three of the seven years of operation river flows were less than adequate for proper operation of the spawning channel. During two of these dry periods the B. C. Electric installed temporary pumps

on the spillway at Jones Lake to augment the flow. These water shortages occurred during the upstream migration period and may have deterred some pink salmon from entering the channel.

Biological Assessment

The pink salmon were closely studied over the period of operation of the channel because they were the major species in the stream. The 1961 pink run represents the fourth generation of adult pinks to utilize the spawning channel.

In 1955, 400 pink salmon returned to Jones Creek and spawned in the artificial channel. These were the only survivors of the damaged environment resulting from reduced flows during the construction of the Jones Creek hydroelectric project in 1953, and were the first adult salmon to use the artificial spawning channel. These salmon entered and moved to the upstream limit of the channel and began spawning. Daily counts of live salmon in each section of the channel followed by examination for sex ratio of the "spawned out" dead provided an accurate estimate of the egg deposition.

The following spring a Wolfe-type fry-trap was installed in the channel (Fig. 8) approximately 100 feet upstream of its confluence with the channel and a total of 158,436 fry were counted as they left the channel on their migration toward the ocean. This represents a survival of 37 per cent. Survival from egg to fry recorded from naturally spawning pink salmon in British Columbia streams has ranged from less than one per cent to 23 per cent. It is generally accepted that pink fry output from an average stream is approximately 10 per cent. It should be pointed out that the 37 per cent survival was obtained despite extreme freshet conditions in November, 1955.



FIGURE 8. The Wolfe-type fry enumeration trap in the spawning channel.

In 1957, a counting fence (Fig. 9) was installed in the channel at the site of the fry trap. This enumeration method replaced the daily section-by-section spawning count employed in 1955 and was considered necessary for an accurate estimate of egg deposition if a run larger than that of 1955 were to occur. By counting the fish moving through the fence and estimating the numbers spawning below the fence a total of 1456 adult pinks were recorded.

The downstream migrating pink fry trapped in the spring of 1958 totalled 363,169. Based on an estimated egg deposition above the fence of 947,000, this represents a survival of 38.4 per cent.



FIGURE 9. *The adult enumeration fence in the spawning channel.*

In 1959, a total of 2604 adult pink salmon returned to Jones Creek. Of these 2119 spawned in the channel providing a deposition of 1,522,980 eggs above the fence. In the spring of 1960 a fry count of 958,000 was recorded. This egg-to-fry survival of 63 per cent, a significant increase over the two previous years, was attributed to excellent incubation conditions resulting from the thorough gravel cleaning operation carried out immediately prior to the spawning period, and to the exceptionally moderate winter conditions.

Table III summarizes this data and points out the steady increase in the adult return and the consistently high survival to fry.

Thus with two years of good egg-to-fry survival the pink run has increased from 400 to 2604. If the fry-to-adult returns recorded in 1957 and 1959 apply the spawning population should approach its pre-development level this year. It is recognized that the effect of variations in ocean survival, fishing pressure and other factors are likely

Table III. Fry Survival and Adult Return of Pink Salmon at Jones Creek

Year	Total number of spawners	Number spawning above counting fence	Eggs deposited above counting fence*	Fry output	Percent survival
1955.....	400	400	428,000	158,436	37.0
1957.....	1,456	1,056	947,000	363,169	38.4
1959.....	2,604	2,119	1,519,000	958,581	63.0

* Based on an average of 1700 eggs per female.

to be overriding, but it is believed that the excellent natural fry production from the channel will enable it to support runs at least equal to those occurring before construction of the hydro project.

Complete data for the chum run spawning in the channel in 1955 showed an egg-to-fry survival of 30.1 per cent and limited observations in the ensuing years indicate that the artificial spawning channel has produced equally high egg-to-fry survivals for this species.

Considerable information on depth, velocity and gravel qualities required for spawning salmon and incubating their progeny was obtained from the operation of this channel. This information was used in designing the Robertson Creek spawning channel recently completed by the Department of Fisheries (Lucas, 1960). The first program in this newly completed channel illustrated the value of this information when a recorded 95 per cent eyed-egg-to-fry survival of pink salmon was measured in 1960 (MacKinnon, 1960).

Conclusion

The operation of the spawning channel over a seven-year period has shown a history of relatively low cost, high fry survival and increasing adult returns. For these reasons it is considered that the channel is a satisfactory solution to the fisheries problem created by the Jones Creek hydroelectric development.

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The Effects on Salmon of a Program of Forest Insect Control with DDT on Northern Moresby Island

by

I. S. Todd and K. J. Jackson

Department of Fisheries of Canada, Vancouver, B.C.

Abstract

An aerial spray program was proposed in 1960 on 31,500 acres of forest land on Northern Moresby Island which was threatened by an infestation of black-headed budworm, *Acleris variana* (Fern.). Before the main program was undertaken, a spraying experiment was performed on a small part of the main spray area at Sachs Creek, to determine the best methods of application and the possible effects of the proposed dosage of DDT on resident fish populations. The main spray program followed this, utilizing a dosage of 0.25 lb. of non-emulsified DDT per U.S. gallon of fuel oil per acre. The spray was applied in such a manner as to avoid spraying directly an area averaging one-half mile on either side of the main stem of each of the major salmon streams involved. The assessment indicated that there was no significant loss of resident juvenile salmonids or of stream bottom fauna which comprise a major portion of the diet of young salmon. In addition, an experiment was conducted using *Bacillus thuringiensis* on a small area which included a salmon stream. No mortality to resident juvenile coho salmon occurred as a result of this spraying at the concentration used.

Introduction

The Forest Biology Service of the Canada Department of Agriculture* conducted egg and larvae surveys during 1959 which revealed the presence of a potentially hazardous black-headed budworm, *Acleris variana* (Fern.) population on northern Moresby Island, British Columbia (Fig. 1). The areas involved contained valuable stands of immature and mature hemlock which necessitated the decision by the Pest Control Committee of the British Columbia Loggers' Association to implement a DDT control program over 31,500 acres, to be carried out during June and July of 1960.

Of the several productive salmon streams which flow through the proposed spray area (Fig. 2), the Copper, Pallant and Deena Rivers are the most important. The Pallant and Deena have an average annual spawning escapement of two to five thousand coho salmon, while that of the Copper River has been estimated at 10,000 fish. These rivers support important populations of other anadromous salmonids, but seaward migration of these was completed by the time of spraying.

In view of the importance of the salmon streams, and in consideration of the high mortality recorded during the 1957 northern Vancouver Island black-headed

* Canada Department of Forestry, as of December 1960.

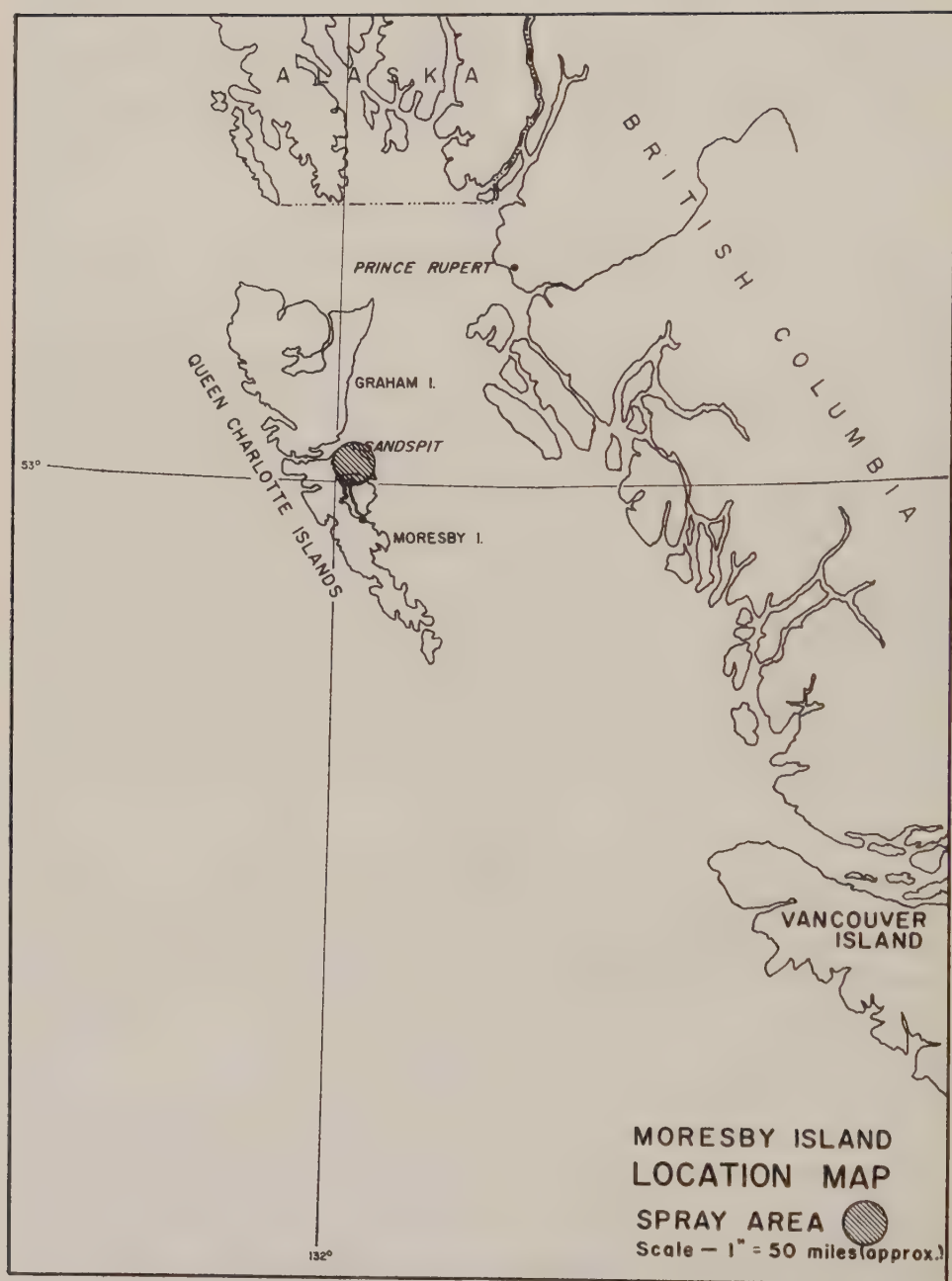


FIGURE 1. Location map of the Queen Charlotte Islands showing Moresby Island and the spray area.

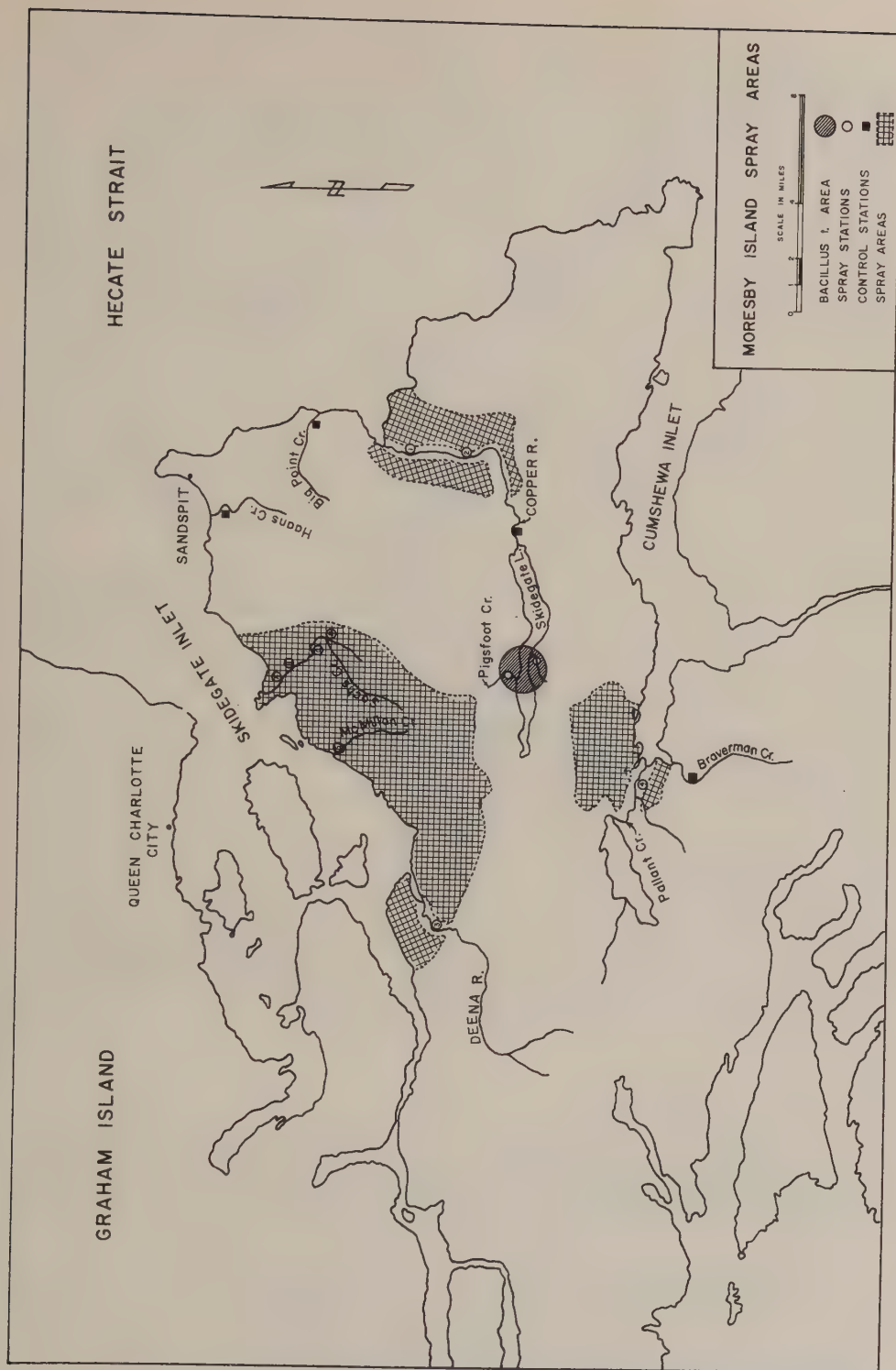


FIGURE 2. Map of northern Moresby Island showing spray areas, salmon streams involved, and *Bacillus thuringiensis* experimental area.

budworm control program (Crouter & Vernon, 1957), representatives of the Forest Industry, the Forest Biology Laboratory of the Canada Department of Agriculture, the Fish and Game Branch of the British Columbia Department of Recreation and Conservation, and the Department of Fisheries, Canada agreed to reduce the dosage rate from one pound DDT per U.S. gallon of fuel oil per acre to 0.25 lb. DDT per U.S. gallon of fuel oil per acre, and to delete the emulsifier which was used in the 1957 spray formulation. Reduction of the dosage to 0.25 lb. DDT per U.S. gallon of fuel oil per acre was prompted by reports from the Federal Interdepartmental Committee for Forest Insect Control which indicated that the hazard to Atlantic salmon parr was lessened by reducing the dosage rate.

Reconnaissance flights over the spray areas were made prior to spraying by Project Co-ordinator H. A. Richmond, the pilot of the spray aircraft, and representatives of the Department of Fisheries to define the boundaries around each major drainage area. Natural landmarks which helped to define these boundaries were noted so that every effort might be made to avoid the direct spraying of the Pallant, Deena, and Copper Rivers. The nature of the terrain and the density of the forest prevented use of this method over the smaller salmon-producing streams.

The responsible agencies also decided to carry out an experiment at Sachs Creek (Fig. 3) prior to the main control program so that specific information on the effects of the reduced dosage of DDT upon fry of Pacific salmon might be recorded. During the preliminary experiment, the feasibility of removing a significant proportion of the oil-spray formulation floating on the stream surfaces was also examined.

Upon completion of the main control program, *Bacillus thuringiensis*, reportedly non-toxic to fish and a possible substitute for DDT, was tested on two plots of immature hemlock which were infested with black-headed budworm (Fig. 2).

For the purposes of this report the 1960 Moresby Island black-headed budworm control program will be treated as three separate units: firstly, the Sachs Creek experiment designed to assess the most suitable methods of applying the spray in relation to salmon streams and the possible effects of 0.25 lb. of DDT per U.S. gallon of fuel oil per acre on resident salmon fry; secondly, to assess the effects of the main black-headed budworm control program; and thirdly, to assess the effects of *Bacillus thuringiensis*, a possible substitute for DDT, on resident salmon fry.

Methods

A. Sachs Creek Experiment

The spray was applied by a Grumman Avenger aircraft in the full formulation of 0.25 lb. per U.S. gallon of fuel oil per acre. Two full swaths were applied, one on either side of Sachs Creek through the pre-defined area, to ensure satisfactory coverage (Fig. 3.).

Four livebox stations were established in the stream as follows (Fig. 3):

- (a) Station A—downstream from the spray area boundary.
- (b) Station B—above the downstream spray area boundary.
- (c) Station C—at the approximate centre of the spray area.
- (d) Station D—upstream from the upper spray area boundary.

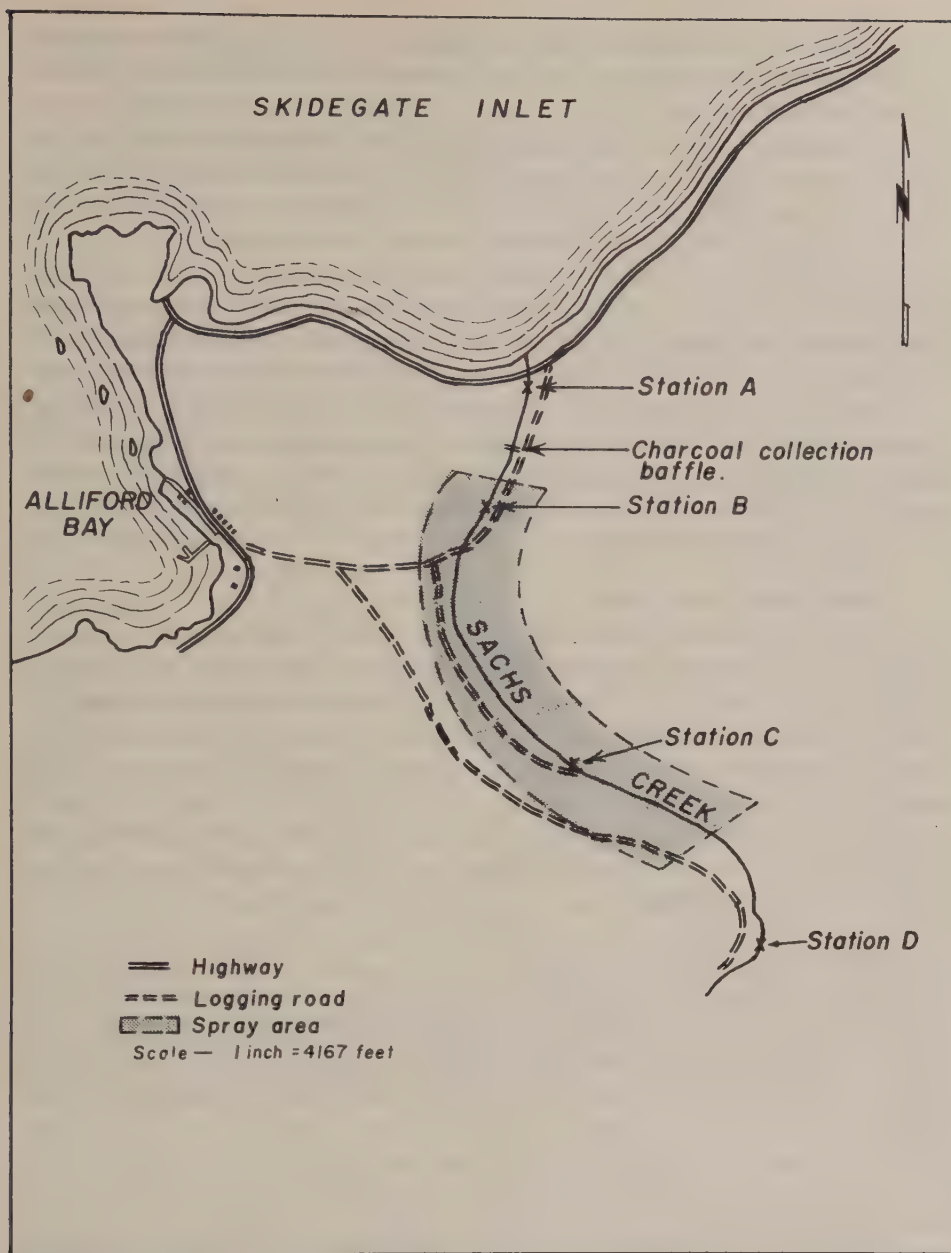


FIGURE 3. Location of the Sachs Creek experimental program including spray area, livebox stations, and charcoal collection baffle site.

Each station consisted of the following:

- One 2' × 2' × 3' standard covered livebox.
- One 2' × 2' × 3' standard open livebox with a half baffle four inches under water to provide optional cover for the penned fry.

- (c) One series of stacked liveboxes by means of which coho fry were confined to specific depths of surface to six inches, six to twelve inches, and twelve to thirty inches.

The standard liveboxes were stocked with approximately 100 coho fry each, the surface to six-inch and six- to twelve inch with 25 fry each, and the twelve- to thirty-inch liveboxes with 50 fry. Few fry were available in the stream, so it was necessary to stock all stations with coho fry obtained from the Copper River.

Samples of aquatic insects and insect larvae from 10 square feet of the stream bottom were taken by Surber stream sampler before and after the spray treatment; and on the morning of treatment, spray assessment cards to measure the coverage of DDT were placed at all stations and at other selected points within the experimental area.

A charcoal baffle collection system consisting of two logs felled across the stream approximately 15 feet apart at a slight angle to the current was established between Stations A and B (Fig. 3) and approximately 25 pounds of charcoal was placed upstream of each baffle. Quart samples of charcoal taken from each baffle 48 hours after treatment were preserved for later analysis.

B. Control Program Assessment

Livebox stations were established at two locations on the Copper River and at one location on the Deena, Pallant, and in two of the smaller less productive streams within the spray area (Fig. 2). Control stations were established in Haans Creek, Big Point Creek, Braverman River, and the Copper River upstream from the spray area. Each of these stations was equipped with liveboxes identical to those used for the experimental study at Sachs Creek.

The bottom sampling procedure employed at the Sachs Creek experiment was repeated in the control program assessment. Spray assessment cards were also placed in the area prior to treatment.

C. *Bacillus thuringiensis* Experiment

Small liveboxes were placed in streams flowing through the experimental plots several days prior to treatment (Fig. 2), and each was stocked with 60 native coho fry. Bottom samples were taken from Pigsfoot Creek the morning prior to treatment and again one week later. Spray assessment cards were placed in strategic positions throughout the area.

Results and Discussion

A. Sachs Creek Experiment

The spray was applied on June 23, and subsequent examination of the spray assessment cards showed that the concentration was adequate to effect budworm control throughout the treatment area. Station A received a light dosage as a result of wind drift, Station B a medium dosage, Station C a heavy dosage, and Station D, which was intended as a control, was lightly contaminated with the spray material as a result of wind drift.

Coho fry were stocked in Stations A and B eleven days prior to spraying, and in C and D eight days prior to spraying. The mortalities recorded in each type of livebox at each station are shown in Tables I to IV. The holding mortality for each type of

livebox was calculated from the percentage daily mortality recorded at all stations within the spray areas before treatment, and at control streams outside the spray areas throughout the entire treatment period. The percentages listed as combined mortalities include actual holding mortality and mortality attributable to the effects of DDT in the treatment area.

Tables I and II show the calculated holding mortalities and the observed combined mortalities for Stations A and B respectively. It will be noted that with the exception of the top livebox of the vertical series at Station B, the combined mortalities at each station did not exceed the calculated holding mortalities at any time. It is significant, however, that after five days the combined mortality in the top livebox at Station B became markedly greater than the calculated holding mortality, indicating that mortality attributable to DDT occurred only in the upper six inches at this particular station.

Table III shows that Station C, which received the heaviest recorded dosage, incurred the heaviest mortalities attributable to DDT. It is to be noted, however, that with the exception of the open livebox and the top livebox of the vertical series, where mortalities occurred within 24 hours, results obtained at Station C were comparable to those recorded at Stations A and B. While it might seem surprising that mortality in the open livebox was comparable to that recorded in the top livebox of the vertical series, it should be noted that water levels in the stream had receded to the point where there was approximately eight inches of water in the former, so that conditions were nearly identical.

Station D, which was planned as a control station above the upstream limit of the treatment area, was contaminated by wind drift, but spray deposition in the immediate area was very light and was not considered to be sufficient to constitute a critical dosage. Table IV shows that mortalities in all liveboxes except the covered one remained below the calculated holding mortality.

The spray observed floating as a slick at Sachs Creek was much less than that observed in 1957 on streams such as the Keogh River, following the DDT spraying in the northern Vancouver Island area. Furthermore, there was no evidence of coho fry and trout feeding voraciously on floating dead insects which had fallen into the river, as had been observed on the Keogh River in 1957. A deliberate search, undertaken after the spraying, failed to reveal any dead indigenous salmonids or aquatic insects in Sachs Creek. While marked mortality attributable to spraying was noted for upper liveboxes in the stacks at Stations B and C, which were most heavily exposed, it is interesting to note that differences were small or negative between holding and combined mortalities at all stations for the open and covered conventional liveboxes, and for stacked liveboxes deeper than six inches below the surface. It would appear, therefore, that only those fish which were forced to remain near the surface came into contact with lethal concentrations of DDT. Although coho salmon fry while feeding are known to make frequent excursions to and from the surface, the absence of an observed mortality to indigenous fish and aquatic insects, and the survival of fish held in conventional liveboxes, free to select a preferred depth, suggest that few fish were contacted by lethal concentrations of DDT.

Laboratory analysis of the charcoal samples taken from each collection baffle showed 10 ppm DDT in the downstream baffle, and less than one ppm in the charcoal

taken from the upstream baffle. This is the reverse of what might have been expected; that is, that the greater amount of DDT should have been extracted at the upstream rather than the downstream baffle.

As a result of this analysis, the methods used to determine the quantities of DDT were checked by the application of a known amount of DDT to a quantity of pure charcoal. Analysis of the treated charcoal produced an equivalent amount of DDT. Thus, a logical explanation for the unexpected reversal of results might be that the samples were incorrectly labelled in the field. Regardless of the position at which extraction occurred, the fact that DDT was extracted at the rate of 10 ppm is significant, as it is known to be lethal to coho fry at a concentration of only one ppm. The collection of 10 ppm DDT in 48 hours following treatment also upholds the mortality differences to coho fry contained in the surface to six-inch depth liveboxes at Stations A and B.

The general results obtained from the charcoal collection baffles would indicate that an added margin of safety might be obtained in future by skimming DDT off the surface of many small streams with strategically placed baffles.

Bottom samples taken at Stations A, B, and D showed no significant changes in population trends after treatment (Figs. 4, 5). The results of all bottom sample analyses are discussed more completely in a following section of this report.

B. Control Program Assessment

From the results of the Sachs Creek preliminary assessment, it was expected that the hazard to resident salmonids would be relatively light at dosages of 0.25 lb. DDT per U.S. gallon per acre. However, to ensure the least possible damage, it was decided with the consent of all agencies involved to eliminate strips approximately one-half mile wide on either side of the main stems of the Pallant, Deena and Copper Rivers as shown in Fig. 2, to avoid direct deposition of DDT on the streams. In addition portions of the planned spray area near the Copper River were not treated, and other areas equally infested by budworm but not influencing salmon streams were substituted. During the operation smoke bombs were utilized to pinpoint streams and establish ground wind drift conditions.

After delays caused by poor weather, spraying commenced on July 17 and the operation was completed by July 23. As a result of the previously described precautions, the main stems of the Pallant, Deena, and Copper Rivers were free from direct spray. Small amounts of drift were recorded throughout the spraying, but the concentration of DDT reaching the streams was extremely low. It is possible that had weather conditions been ideal rather than marginal, even these minor drift effects might have been eliminated.

1. Coho Fry Mortality in Liveboxes

Station 1, on the Lower Copper River, was located approximately one mile from tidal influence. Spray assessment cards located in the area showed a very light deposit when examined two hours after spraying. This deposition was typical throughout the six miles of river passing through the spray area. An examination of Table V shows negative differences between combined and holding mortalities for the covered and open conventional liveboxes. Combined mortality in the vertical series was observed at all levels. The heavy mortality in the surface to six-inch depth livebox might be attributed to DDT but the reason for the mortality in the lower liveboxes is uncertain.

Station 2, on the Middle Copper River, was located in the approximate middle of the spray area. Again assessment cards in the area recorded only traces of spray. As may be observed from Table VI, combined mortality in all five liveboxes was greater than the calculated holding mortality. It would be misleading, however, to conclude that the high combined mortality in this case could be attributed to the effect of DDT, for this station was placed in a position where there was considerable velocity change during high water just prior to treatment, and this possible effect on the fish was compounded by the fact that the coho fry had been held for 15 days prior to treatment. Furthermore, a small stream on the opposite bank of the Copper River, which contained large numbers of coho salmon and steelhead trout fry was examined both before and after treatment, and at no time were dead or distressed fish observed. This stream was checked within two hours of spraying, and fish were not observed feeding on dead floating insects. That resident fish survived is opposed to the fact that experimentally exposed fish died, and although a reason for the contradiction is offered it is considered that data obtained from this station was inconclusive.

Station 3, on the Deena River, was positioned approximately one mile upstream from tidal influence. Spray assessment cards placed in the area showed very slight traces of spray, similar in amount to that observed at the Copper River stations. Again, as could be expected from the Sachs Creek assessment, combined mortality exceeding holding mortality was noted only in the top livebox of the vertical series.

Station 4, on the Pallant River, was located two hundred yards above tidal influence but due to the shallow nature of the available pool, the vertical series of liveboxes had to be placed at the edge of the main current, and it is possible that high discharges experienced shortly before the treatment date weakened the confined fish. Spray assessment cards in the area recorded greater contamination than at other stations, although the area was not directly sprayed. Mortality recorded in the five liveboxes as shown in Table VIII indicates a trend not unlike that observed at Sachs Creek in the open, covered and surface vertical livebox. Unexpectedly high mortalities were recorded, however, in the six- to twelve-inch, and in the twelve- to thirty-inch liveboxes, but this dissimilarity might be attributed to the effect on the fish of high water velocity in Pallant River, rather than to the effects of the DDT.

Station 5 was located on MacMillan Creek, a short distance upstream from tidal influence. The limited depth of this stream precluded placement of a vertical livebox series, so an open livebox was placed in approximately twelve inches of water in a densely overgrown portion of the stream. Spray assessment cards located on a nearby road indicated that a dosage of 0.25 lb. DDT per U.S. gallon of fuel oil per acre had been deposited on the stream. Results listed in Table IX show a small positive difference between combined and holding mortality. Following spraying, an examination of the stream in the vicinity of the station failed to reveal any signs of distressed, or dead, fish or insects.

Station 6, on Sachs Creek, was stocked at the same position as Station A (Preliminary Assessment). In this instance, the DDT deposition was very light, and contamination of the stream was due to wind drift only as there was no direct spraying in the immediate vicinity of the station. The results listed in Table X indicate no effect upon the fish in the liveboxes.

2. Bottom Organism Samples

In previous forest insect control programs using emulsified formulations, substantial but varied declines have been incurred by aquatic larval insect forms (Ide, 1956, Crouter & Vernon, 1957). In an effort to assess the possible effects of the 0.25 lb. per acre DDT dosage used on Moresby Island, stream bottom samples were taken at intervals throughout the study period. Each sample consisted of organisms obtained from ten square feet of stream bottom by means of a Surber sampler. These were taken in the vicinity of livebox stations on all control streams and on the Copper, Deena, Sachs, and Pallant Rivers in the treatment area.

Samples taken prior to the spray periods indicated normal population trends and fluctuations. Fig. 4 compares the average incidence of stone fly (Ephemeroptera), mayfly (Trichoptera) and caddisfly (Plecoptera) larvae for the Sachs Creek experiment, with major spray area streams and control streams. The three orders mentioned above were the larger forms present and as such provide a major portion of the diet of juvenile salmonids.

Spray periods are shown in Fig. 4 and it is noteworthy that none of the three orders of insects exhibited significant declines after DDT treatment. While all populations showed a definite decline, this trend was well established prior to spraying, and continued after the spray period as exhibited by the results obtained from the control streams.

Total dry weights of the bottom samples for each station were averaged and separated into pre-spray and post-spray weights. A definite decline was recorded in the spray areas, however similar declines were evident in the control streams (Fig. 5). These results would suggest this decline was general to the insect populations rather than being caused by the DDT spraying.

Table XI lists the average weight in grams per square foot of pre-spray and post-spray bottom samples in Sachs Creek, in the main spray areas, and at the control stations. The greater of the two values recorded as post-spray weights for Sachs Creek is the average of all samples for all stations; the lesser is the over-all average excluding two samples taken at Station A. The extreme difference in the weights was due to a sudden population increase of Amphipods which appeared at Station A and lasted for the two sampling periods only, thus weighting the results significantly. The other stations indicated an average decline as shown by the lesser average weight.

There is, then, no evidence from the bottom samples that the non-emulsified formulation containing 0.25 lb. of DDT per acre applied in the manner described had any measurable immediate effect upon typical aquatic insect larvae indigenous to Moresby Island streams. Assessments of other control programs (Ide, 1956, Crouter & Vernon, 1957, Kerswill, 1956, 1957) have shown immediate reductions to stream insect life when DDT was applied at one pound per acre in an emulsified formulation. In the instances cited, recovery of the larger important forms was extremely slow, possibly because these forms were eradicated from individual drainage areas that were almost entirely contaminated. In the Moresby Island program, large parts of the major drainage areas remained unsprayed; and if the more subtle effects of DDT resulted in an undetected or a delayed mortality a rapid recovery of stonefly, mayfly,

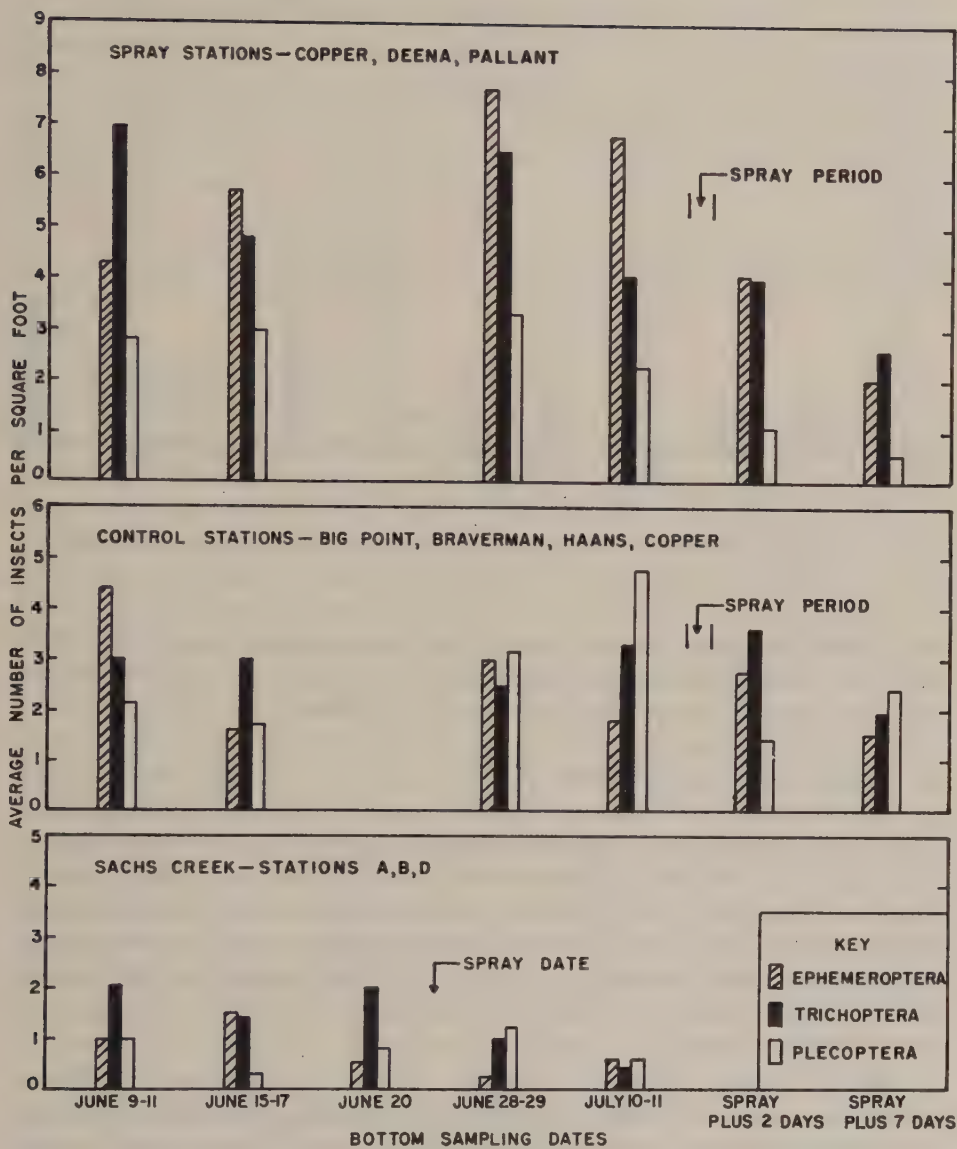


FIGURE 4. The average numbers of Ephemeroptera, Trichoptera, and Plecoptera per square foot of stream bottom in spray area and control areas before and after spraying.

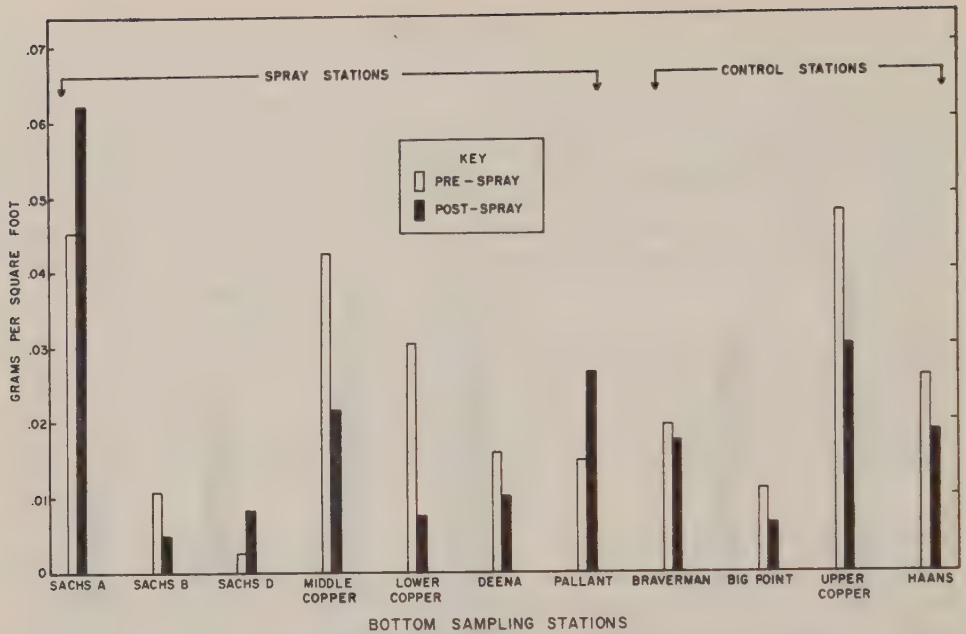


FIGURE 5. The average dry weight per square foot of stream bottom organisms in pre-spray and post-spray sampling periods.

and caddisfly larvae should occur by recruitment from headwater areas. Field observations did not reveal any numbers of dead or dying insects on stream surfaces so it may be assumed that the adult insect kill was also relatively light.

C. *Bacillus thuringiensis* Experiment

After completion of the budworm control program two plots of immature hemlock infested with black-headed budworm were sprayed with *Bacillus thuringiensis* at the rates of 2.7 lb. in 1.8 U.S. gallons of fuel oil per acre and 4.0 lb. of thuricide in 2.7 gallons of fuel oil per acre. Small streams containing resident coho and steelhead fry flow through both plots. A livebox containing 60 coho fry was installed in each stream the day before treatment and bottom samples were taken. The liveboxes were checked periodically during the week following treatment, and no fry mortality was recorded in either stream.

Results of a bio-assay conducted by the Fisheries Research Board of Canada indicated that for the above described formulation of *Bacillus thuringiensis* the toxicity to juvenile salmon is extremely low (personal communication). The possibility of using this insecticide in the vicinity of salmon streams in future forest insect control programs should be investigated.

Bottom samples of organisms were taken a few hours prior to treatment on one stream (Fig. 3) and one week after treatment. Dry weight results are listed in Table XI, and it may be observed that no effects on bottom fauna were recorded. No evidence of distressed or dead resident fry was observed.

Conclusions

A. *Sachs Creek Experiment*

The major conclusions arising from the Sachs Creek experiment were:

(1) Damage to resident fish populations apparently can be decreased by eliminating an area on either side of the main stems of major streams from direct spraying.

(2) The effects on resident fish populations of a non-emulsified formulation of 0.25 lb. DDT per U.S. gallon of fuel oil per acre applied in the manner described were significantly less than the effects recorded on northern Vancouver Island where a one-pound emulsified formulation was used.

(3) The possibility that non-emulsified spray can be removed from small streams by strategically placed charcoal collection baffles in sufficient quantity to give practical results should be further investigated.

B. *Control Program Assessment*

Field observations did not indicate that a loss of resident fish occurred, and analysis of bottom sample data shows that the abundance of aquatic fauna was not significantly affected. The results of this program contrast sharply with the very heavy mortalities recorded during the 1957 control program on northern Vancouver Island (Crouter & Vernon, 1957), at which time heavy oil slicks and large numbers of dead and distressed aquatic insects and resident fish were observed. The results would indicate that if there was any mortality attributable to the spray program, it was light. While simple subtractions of holding mortality from combined mortality sometimes show high mortality attributable to DDT in top vertical liveboxes (e.g. Sachs Creek, Station C, 30 per cent and Pallant River, Station 4, 55 per cent), little or no mortality was shown in the lower liveboxes of the vertical series. The lower liveboxes probably best reflect the effect upon fish following spraying, especially since these results agree with the observed survival of resident fish of the same size and species. However, the fact that there were marked mortalities in the upper liveboxes at Stations C and B at Sachs Creek illustrates that there could be a real danger to salmon fry which might come in contact with DDT applied to a river even at a concentration as low as 0.25 lb. per acre. This is understandable in view of the work of Alderdice and Worthington (1959) who showed that DDT is toxic to young salmon at a concentration of 0.05 ppm. The assessment showed that it is practical to plan and to execute spray programs which will result in a minimum of DDT entering streams inhabited by salmon and trout.

The avoidance of a serious kill of salmon and trout on northern Moresby Island was due to the effective co-operation and field liaison between the Pest Control Committee of the British Columbia Loggers' Association, the Forest Biology Laboratory of the federal Department of Agriculture, and the Department of Fisheries which resulted in: (1) adherence by the aircraft pilot to boundaries established on the Copper, Deena, and Pallant Rivers; and (2) use of a dosage of 0.25 lb. per U.S. gallon of fuel oil per acre in accordance with the recommendations of the Interdepartmental Committee for Forest Insect Control.

C. *Bacillus thuringiensis* Experiment

The application of a fuel oil formulation of *Bacillus thuringiensis* in two concentrations to plots of immature hemlock apparently caused no mortality to resident coho fry or to aquatic insects upon which they feed. From these results, further studies should be undertaken in an effort to produce a practical and economical formulation of this or other insecticides in order to reduce the hazard to resident salmon populations. Even if it is less economical than DDT, such a formulation could have use for application to areas paralleling salmon streams to ensure effective fisheries protection, and at the same time provide satisfactory forest insect control.

Table I. Sachs Creek Experiment—Coho Fry Mortality
Station A

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	1.1	0	.8	0	12.2	0	(17.3)	0	9.2	0
2.....	2.0	0	.9	0	22.2	0	22.3	0	13.7	2.0
3.....	(2.4)	0	1.8	0	23.5	0	31.6	8.0	15.7	2.0
4.....	2.7	0	(3.6)	0	25.5	0	39.6	8.0	25.7	2.0
5.....	(2.9)	0	(5.4)	0	(26.3)	0	(42.0)	(10.0)	(26.9)	(5.0)
6.....	3.1	0	(7.2)	0	(27.1)	0	(44.4)	12.0	(28.1)	7.0
7.....	(5.3)	0	(9.0)	(.9)	(27.9)	(8.0)	(47.8)	(24.0)	(29.3)	(15.0)
8.....	7.2	0	(10.8)	1.8	(28.7)	16.0	(49.2)	36.0	(30.5)	23.0
9.....	(9.6)	(3.2)	12.6	(4.5)	29.5	(28.0)	51.6	(42.0)	31.7	(28.0)
10.....	(12.0)	6.4		7.3		40.0		48.0		33.0

Table II. Snake Creek Experiment. Chub Fry Mortality
Station B

Days After Spawning	Cumulative % Mortality in Larvae Types											
	Open				C ₁				C ₂			
	Hatching	Continued	Hatching	Continued	Hatching	Continued	Hatching	Continued	Hatching	Continued	Hatching	Continued
1	1.4	0	0	0	12.2	11.8	(17.3)	0	9.2	0	0	0
2	2.0	0	0	0	22.2	11.8	22.3	0	13.7	0	0	0
3	2.4	0	1.6	0	23.8	23.0	31.6	0	18.7	0	0	0
4	2.7	0	2.6	0	28.8	26.2	39.6	0	25.7	0	0	0
5	2.9	0	3.4	0	36.3	36.6	42.5	0	(26.9)	0	(3.0)	0
6	3.1	0	7.2	0	(27.4)	46.9	46.8	0	(22.5)	0	2.5	0
7	3.3	0	7.5	0	(27.6)	47.9	47.8	(4.0)	(29.3)	(7.0)	(7.0)	0
8	7.2	0	10.2	1.2	(22.7)	49.2	49.2	(49.2)	(2.8)	12.6	12.6	0
9	7.6	0	12.6	2.7	30.8	52.3	51.6	(12.0)	31.7	(13.6)	(13.6)	0
10	12.4	1.2	14.5	3.6		57.8		16.9		24.0		0

Table III. Static Check Experiment - Ohio River Mainway
Station C

Diss. Area Spacing		Contribution of Movement to Lockness					
		Covered		Open		Total	
		Hiding	Concealment	Hiding	Concealment	Hiding	Concealment
1.....	0		1.0	.0	8.8	28.0	11.0
2.....	.0		4.8	.0	8.8	28.0	11.0
3.....	(1.0)		4.8	.0	8.7	44.0	28.0
4.....	1.1		4.8	.8	10.6	44.0	28.0
5.....	2.0		4.8	.0	(11.0)	44.0	28.0
6.....	(2.0)		4.8	1.8	12.8	44.0	28.0
7.....	2.5		4.8	(3.0)	(13.0)	44.0	28.0
8.....	(2.0)		4.8	(5.0)	(26.5)	44.0	28.0
9.....	3.1		(8.0)	7.0	(27.1)	(52.0)	44.0
10.....	(5.5)		8.7	(9.0)	(27.0)	60.0	52.0

Table IV. Sachs Creek Experiment—Coho Fry Mortality
Station D

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	.9	3.6	(.5)	0	5.4	8.0	6.8	0	(3.9)	0
2.....	(.9)	4.6	(.6)	0	5.8	8.0	(9.3)	0	(6.1)	0
3.....	(1.0)	4.6	.6	0	9.2	8.0	12.3	0	8.2	0
4.....	1.1	5.6	.8	0	12.2	8.0	(17.3)	4.0	9.2	0
5.....	2.0	(5.6)	.9	0	22.2	(8.0)	22.3	(4.0)	13.7	0
6.....	(2.4)	5.6	1.8	0	23.5	8.0	31.6	4.0	15.7	0
7.....	2.7	(6.4)	(3.6)	(.5)	25.5	(8.0)	39.6	(8.0)	25.7	0
8.....	(2.9)	7.3	(5.4)	.9	(26.3)	8.0	(42.0)	12.0	(26.9)	6.0
9.....	3.1	(7.8)	(7.2)	(.9)	(27.1)	(10.0)	(44.4)	(16.0)	(28.1)	(11.0)
10.....	(5.3)	8.2	(9.0)	.9	(27.9)	12.0	(47.8)	20.0	(29.3)	16.0

Table V. Control Program Assessment
Station 1—Lower Copper River

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 0"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	(2.9)	2.9	(5.4)	0	(26.3)	20.0	(42.0)	32.0	(26.9)	34.0
2.....	3.1	3.6	(7.2)	0	(27.1)	44.0	(44.4)	36.0	(28.1)	36.0
3.....	(5.3)	(5.4)	(9.0)	0	(27.9)	(49.6)	(47.8)	(42.4)	(29.3)	(40.4)
4.....	7.2	(7.2)	(10.8)	0	(28.7)	(55.2)	(49.2)	(48.8)	(30.5)	(44.8)
5.....	(9.6)	(9.0)	12.6	0	29.5	(60.8)	51.6	(55.2)	31.7	(49.2)
6.....	(12.0)	(10.8)	(14.0)	0		(66.4)		(61.6)		(43.6)
7.....	(14.4)	12.7	(15.4)	.9		72.0		68.0		58.0
8.....	(16.8)		(16.8)							
9.....	(19.2)		(18.2)							
10.....	(21.6)		(19.5)							

Table VI. Control Program Assessment
Station 2—Middle Copper

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	2.7	.9	(3.6)	5.6	25.5	20.0	39.6	44.0	25.7	12.0*
2.....	(2.9)	1.8	(5.4)	9.1	(26.3)	36.0	(42.0)	64.0	(26.9)	20.0
3.....	3.1	(5.2)	(7.2)	(12.4)	(27.1)	(41.0)	(44.4)	(65.6)	(28.1)	(31.6)
4.....	(5.3)	(8.6)	(9.0)	(15.7)	(27.9)	(45.0)	(47.8)	(67.2)	(29.3)	(43.2)
5.....	7.2	(12.1)	(10.8)	(19.0)	(28.7)	(50.0)	(49.2)	(68.8)	(30.5)	(54.8)
6.....	(9.6)	(15.6)	12.6	(22.2)	29.5	(55.0)	51.6	(70.4)	31.7	(66.4)
7.....	(12.0)	19.1	(14.0)	25.5		60.0		72.0		78.0
8.....	(14.4)		(15.4)							
9.....	(16.8)		(16.8)							
10.....	(19.2)		(18.2)							

Table VII. Control Program Assessment
Station 3—Deena River

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	(.2)	0	.1	0	9.2	1.60	12.3	20.0	8.2	2.0
2.....	.3	0	.2	0	12.2	28.0	(17.3)	20.0	9.2	2.0
3.....	(.4)	(2)	.3	0	22.2	(38.4)	22.3	(21.6)	13.7	(2.8)
4.....	.5	(.3)	.4	0	23.5	(48.8)	31.6	(23.2)	18.7	(3.6)
5.....	.5	(.5)	.5	0	25.5	(59.2)	39.6	(24.8)	25.7	(4.4)
6.....	.8	(.7)	(.5)	0	(26.3)	(69.6)	(4.20)	(26.4)	(26.9)	(5.2)
7.....	.9	.9	(.5)	0	(27.1)	80.0	(44.4)	28.0	(28.1)	6.0
8.....	(1.0)		(.6)		(27.9)		(47.8)		(29.3)	
9.....	(1.1)		.6		(28.7)		(49.2)		(30.5)	
10.....	1.1		.8		29.5		51.6		31.7	

Table VIII. Control Program Assessment
Station 4—Pallant River

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	.8	.9	1.1	0	12.2	0	(17.3)	8.0	9.2	2.0
2.....	.9	(1.4)	2.0	0	22.2	(20.0)	22.3	(20.0)	13.7	(9.0)
3.....	1.8	1.8	(2.4)	0	23.5	40.0	31.6	32.0	15.7	16.0
4.....	(3.6)	(3.4)	2.7	0	25.5	(48.8)	39.6	(41.6)	25.7	(21.6)
5.....	(5.4)	(5.1)	2.9	0	(26.3)	(57.6)	(42.0)	(51.2)	(26.9)	(27.2)
6.....	(7.2)	(6.7)	3.1	0	(27.1)	(66.4)	(44.4)	(60.8)	(28.1)	(32.8)
7.....	(9.0)	(8.4)	(5.3)	0	(27.9)	(75.2)	(47.8)	(70.4)	(29.3)	(38.4)
8.....	(10.8)	10.0	7.2	0	(28.7)	84.0	(49.2)	80.0	(30.5)	44.0
9.....	12.6		(9.6)		29.5		51.6		31.7	
10.....	(14.0)	(12.0)								

Table X. Control Program Assessment
Station 6—Sachs Creek (Station A)

Days After Spraying	Cumulative % Mortality in Liveboxes									
	Covered		Open		0" — 6"		6" — 12"		12" — 30"	
	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined	Holding	Combined
1.....	.3	0	0.2	0	5.8	0	(9.3)	0	(6.1)	2.0
2.....	(.4)	0	.3	0	9.2	0	12.3	0	8.2	2.0
3.....	.5	(.15)	.4	(.30)	12.2	(.67)	(17.3)	0	9.2	(2.0)
4.....	.5	(.30)	.5	(.60)	22.2	(1.34)	22.3	0	13.7	(2.0)
5.....	.8	(.45)	(.5)	(.90)	23.5	(20.0)	31.6	0	15.7	(2.0)
6.....	.9	(.60)	(.5)	(1.2)	25.5	(2.67)	39.6	0	25.7	(2.0)
7.....	(1.0)	(.75)	(.6)	(1.5)	(26.3)	(3.34)	(42.0)	0	(26.9)	(2.0)
8.....	(1.1)	.9	.8	1.8	(27.1)	4.0	(44.4)	0	(28.1)	2.0
9.....	1.1		.9		(27.9)		(47.8)		(29.3)	
10.....	2.2		1.8		(28.7)		(49.2)		(30.5)	

Table IX. Control Program Assessment
Station 5—MacMillan Creek

Days After Spraying	Cumulative % Mortality in Livebox	
	Open Livebox	
	Holding	Combined
1.....	(.6)	.9
2.....	.6	(1.8)
3.....	.8	2.7
4.....	.9	(5.4)
5.....	1.8	(8.2)
6.....	(3.6)	(10.9)
7.....	(5.4)	(13.7)
8.....	(7.2)	16.4
9.....	(9.0)	
10.....	(10.8)	

Table XI. The Pre-Spray and Post-Spray Average Dry
Weight per Square Foot of Bottom Organisms

Area	Average Weight in Gr/Ft ²	
	Pre-Spray	Post-Spray
Sachs Creek Experiment.....	.0197	.0085
Spray Program Streams.....	.0260	.0340
Pigsfoot Creek.....	.0052	.0175
Control Streams.....	.0287	.0118
		.0181

Acknowledgments

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Supersaturation of the Water Supply and Occurrence of Gas Bubble Disease at Cultus Lake Trout Hatchery

By

H. H. Harvey

*Institute of Fisheries, University of British Columbia, Vancouver, B.C. and
International Pacific Salmon Fisheries Commission, New Westminster, B.C.*

and

S. B. Smith

*Department of Zoology, University of Alberta, Edmonton and
British Columbia Department of Recreation and Conservation, Vancouver, B.C.*

Abstract

The Trout Hatchery at Cultus Lake, B.C., has been plagued for some years by the erratic appearance of gas bubble disease in the fish. A study of the intake system revealed there were no less than four distinct ways in which the water supply could become supersaturated. These studies are reported that they may serve as object lessons to those involved in the design and construction of hatchery intakes.

The importance of quantitative measurement of both oxygen and nitrogen is also stressed.

Introduction

Marsh and Gorham (1905) contributed the first thorough study of gas disease in fishes and one of the most useful to date. They were able to trace the cause of the disease at Woods Hole to a leaky suction pipe, such that air entered the pipeline supplying the station. On passing through the pump, air and water came under eight pounds of hydrostatic pressure (above atmospheric) and supersaturation of the water resulted. Placed in this water, fish developed gas-filled blebs in the regions of the head and fins. These gas bubbles under the skin did not appear immediately but only after several hours' exposure. Marsh and Gorham observed differences among species as to the nature and onset of symptoms. They postulated that the blood of the fish tended to come to gaseous equilibrium with the supersaturated environment. Release of gas within the vessels was attributed to temperature changes within the blood; the red blood corpuscles supplying nuclei for bubble formation. These bubbles collected in the region of the heart and ventral aorta resulting in fatal embolism. From the data of Marsh and Gorham it appears that the original leaky pipeline was producing sea water with dissolved nitrogen approximately 122 per cent of air saturation.

Marsh and Gorham experimentally prepared supersaturated water with nitrogen content averaging 147 per cent and this water was rapidly fatal to fish, killing hake in eight to 20 hours. Nitrogen saturation of 127 per cent was less rapidly fatal and saturations of 105 per cent were harmless to fish.

Rucker and Tuttle (1948) reported a method of aerating water and reducing nitrogen saturation from 140 to 101 per cent. They noted fish can tolerate nitrogen of about 110 per cent of air saturation. Rucker and Hodgeboom (1953) investigated the Puyallup hatchery spring which delivered water 120 per cent saturated with nitrogen and 80 per cent with oxygen. Trout fry succumbed to gas bubble disease in water of 115 per cent nitrogen saturation. Rucker and Tuttle concluded that water of 110 per cent nitrogen saturation is satisfactory, but that 115 per cent is probably too high for trout.

Egusa (1959) determined experimentally the critical nitrogen level above which characteristic symptoms of gas disease develop over the surface of fish. This he termed the "detrimental nitrogen limit". Above this is the level producing death, which he termed the "lethal nitrogen limit". Both values were based on a response of 50 per cent of the fish. Lethal nitrogen limits range from 120 per cent for carp to 140 per cent for killifish. Appearance of symptoms of gas disease in five per cent of the carp occurred at nitrogen saturations of 116 per cent. Egusa concluded that carp, crucian carp, bitterling, eel and killifish probably could survive indefinitely nitrogen saturations of 115 per cent. Unfortunately comparable studies are not available for trout and salmon; these fish appear to be more susceptible to gas disease than those used by Egusa. Embury (1934) observed trout fry to be afflicted with gas bubble disease where the temperature was raised 5°C. or more. This naturally follows from the rapid decrease in nitrogen solubility with increasing temperature. Thus if water were at 100 per cent of air saturation initially, a 5°C. increase (for example from 5°C. to 10°C.) without gas loss would result in a level of 113 per cent for oxygen and 112 per cent for nitrogen. Embury noted the fry sacs became distended with gas and the helpless fry were buoyed to the surface.

Gas bubble disease in fish has also been attributed to oxygen supersaturation: Plehn (1924), Haempel (1928) and Woodbury (1941) and to carbon dioxide Mrsic (1936). Undoubtedly these gases are of less importance than nitrogen to the hatchery fish culturist. In view of the extreme solubility of carbon dioxide and its effect on fish respiration at relatively low tensions, the conclusions of Mrsic must be regarded with some suspicion. Recently, Bishai (1960) reviewed the literature on the effects of water gas content on young fish.

Experimental Methods

Water analysis for dissolved oxygen and nitrogen was carried out using the apparatus of Scholander, van Dam, Claff and Kanwisher (1955). The technique was modified in order to replace the reagent alkaline pyrogallol with commercially available oxygen absorber. A description of the modified method and calculation of nitrogen analysis in water and blood may be found in Harvey (1961). Theoretical oxygen and nitrogen values were calculated from the absorption coefficients, Handbook of Chemistry and Physics, for an atmosphere composed of 20.95 per cent oxygen and 79.05 per cent nitrogen. The barometric pressure was corrected for water vapor pressure at the temperature of the water sample. The accuracy of the method was such that twenty nitrogen analyses on air-equilibrated distilled water averaged 100.5 per cent of air saturation, with one standard deviation ± 2.1 per cent.

Winkler determinations were performed according to the technique described in Standard Methods for the Examination of Water and Wastewater. Two milliliter

quantities of manganese sulfate, alkaline iodide and sulfuric acid were used throughout in order to assure fixation of oxygen at high gas tensions. Calculations were based on a "wet" gas as described above. The authors have not used the oxygen values of Truesdale, Downing and Lowden (1955) only because similar data on nitrogen solubility were not available. The absorption coefficient tables in the Handbook of Chemistry and Physics are based on the International Critical Tables. A more detailed discussion of this problem may be found in Hutchinson (1957).

Appearance of Gas Disease

During the past several years sudden sporadic outbreaks of gas disease have occurred among trout at the Cultus Lake Hatchery. The disease appeared either during the summer and was associated with low flow and high temperature in the creek supplying the hatchery or during the autumn and was associated with the onset of fall rain, dropping of leaves from trees and occasional power failures. In 1960 a program of study was established calling for periodic Winkler determinations on the hatchery water supply during the summer and fall. One such outbreak of the disease occurred in August of 1960, (Fig. 1) with high mortalities accompanying oxygen saturations

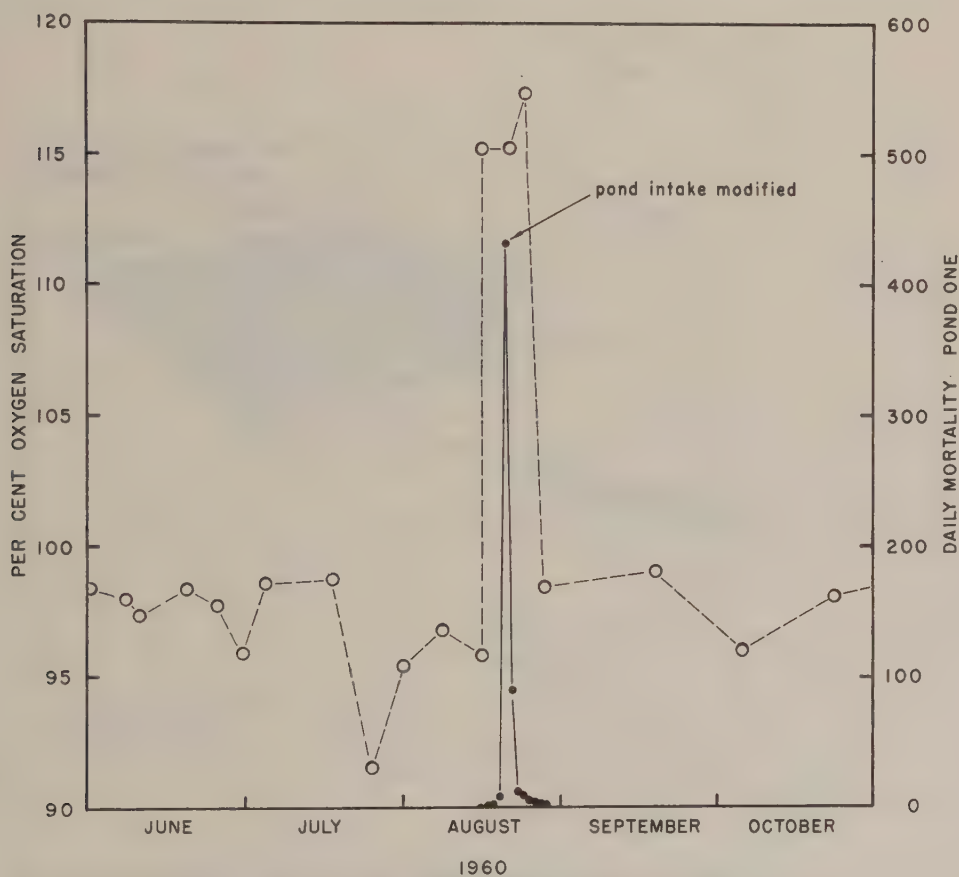


FIGURE 1. Trout mortality accompanying supersaturation of the water supply.

of 115-117 per cent. Concurrent Winkler determinations above the level of the intake indicated the water supply was slightly below air saturation. This study focused attention on the hatchery intake (Fig. 2). The disease outbreak had coincided with the construction of new pipeline supports. During construction the entire creek was allowed to pass through the pipeline in order to dry up the creek bed and hence permit concrete to be poured. This had resulted in the reservoir of the secondary intake being drawn down to a level at which air entered the pipeline. These conditions were duplicated experimentally and nitrogen saturations of 113-136 per cent were recorded.

During the past several years, as attempts were made to increase production of trout at Cultus Hatchery, larger numbers of fish were held throughout periods of low water flows in the creek. Temperatures during these periods reached summer maximum levels resulting in increased fish activity and hence greater oxygen demand by the fish. The absolute level of oxygen in the water was lower through reduced solubility at higher temperature and this, coupled with greater fish demands, resulted in low oxygen

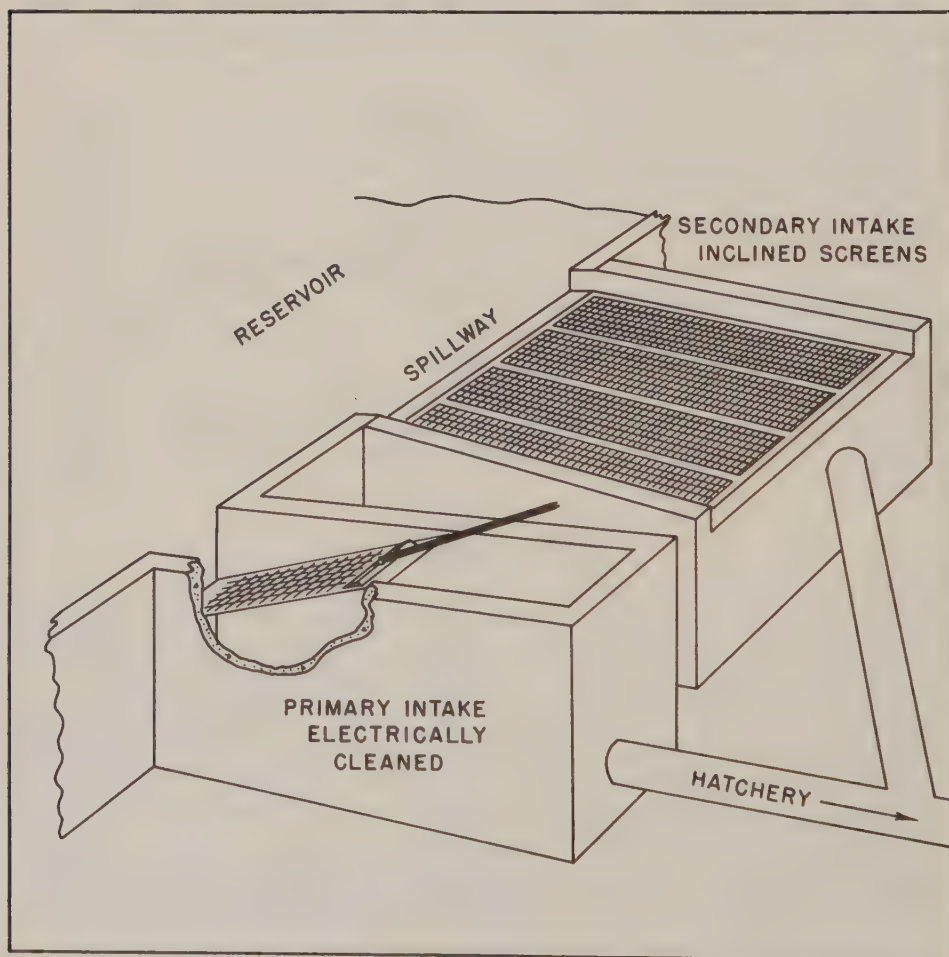


FIGURE 2. Dual intake, Cultus Trout Hatchery (after Harman).

tensions. The hatchery staff has attempted to increase water flows through the rearing facilities by progressively opening the main valve at the lower end of the water system and hence minimize the wasting of water over the spillway. Any reduction in stream flow would thus result in the screen chamber reservoir being drawn down, probably to the level at which air would enter the pipeline (Fig. 3).

That this explanation could not apply in the case of the more common fall mortalities was quite clear. These mortalities had been associated on occasion with power failures and with heavy deposition of leaves on the intake screens during freshets. The investigation was directed at the primary intake (Fig. 4A). This intake is at a slightly lower level than the secondary (Fig. 2) and normal hatchery demands of 2.3 cfs are met entirely by water screened through the primary intake. The secondary intake was designed to meet hatchery requirements in the event of a failure of the primary. This was tested experimentally by progressively occluding the screen of the primary intake and analyzing the water at the bottom of the pipeline for nitrogen and oxygen.

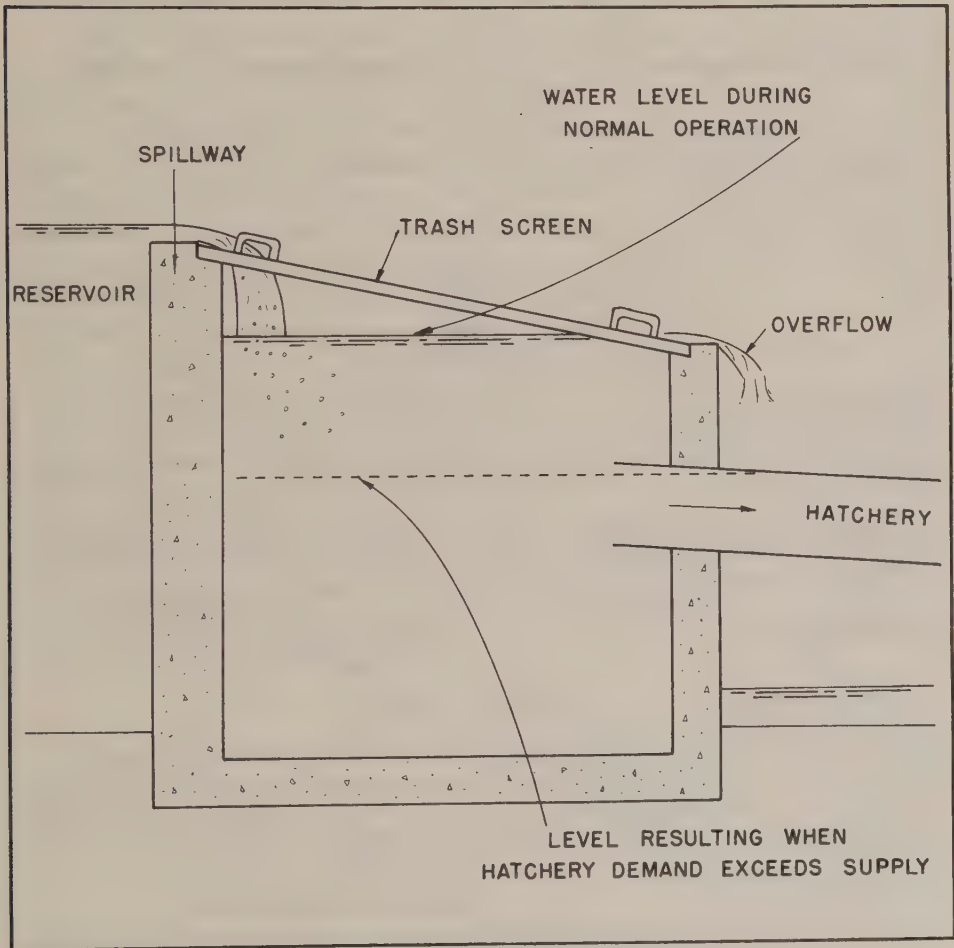


FIGURE 3. Cross section of secondary intake.

Normal operation of the intake system is illustrated in Fig. 4A, with some head loss across the screen but with no impedance of flow in the main line.

Slight blocking of the screen (Fig. 4B) resulted in a further reduction of water level in the chamber behind the screen. Under these conditions a vortex formed periodically and air was drawn down into the intake. Under positive pressure within the pipeline a portion of this air was forced into solution, resulting in a nitrogen saturation of 101-104 per cent at the bottom of the line.

More severe blocking of the screen (Fig. 4C) resulted in still greater head loss across the screen. Water falling through the screen splashed onto the water surface within the intake, producing air bubbles in the water. The water and fine bubbles were drawn into the pipeline as the downward velocity of the water was greater than the buoyant movement of the bubbles upward. Resulting nitrogen saturation ranged from 105-117 per cent, measured at the bottom of the pipeline.

When a large part of the area of the screen was occluded (Fig. 4D) hatchery

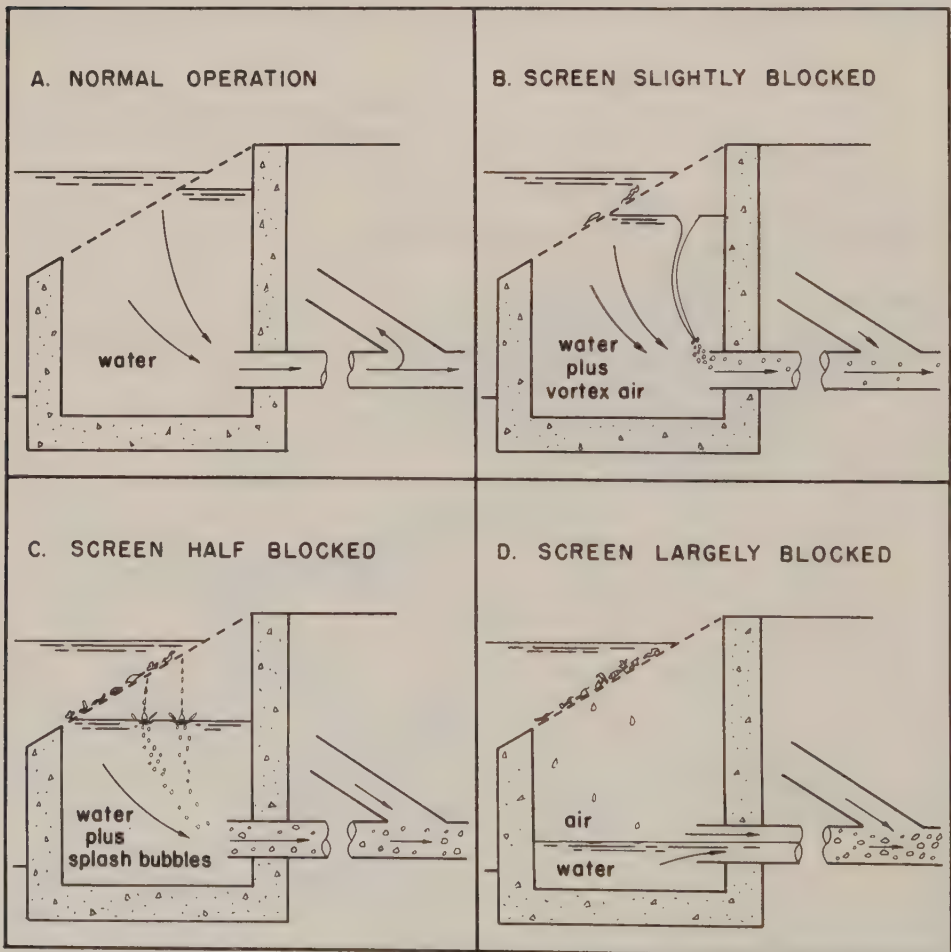


FIGURE 4.—Cross section of primary intake illustrating air contamination with various degrees of screen occlusion.

requirements were met by flow of water from the auxiliary intake. Apparently the velocity of the flow past the junction of the two lines created sufficient negative pressure to draw most of the water from the primary intake chamber and the pipeline to the level of the junction. Under these conditions sufficient air was drawn in through the primary intake to produce nitrogen saturations of 115-130 per cent at the bottom of the pipeline.

Oxygen Nitrogen Relationship

In all these supersaturation studies the oxygen nitrogen relationship in water was altered from the 34:66 ratio toward increased nitrogen. For example, at an oxygen saturation of 110 per cent, the nitrogen saturation would be 120 per cent. Thus the two gases were entering solution not as the products of their solubilities and partial pressures but rather in relation to their partial pressures alone. The gases were not entering into solution completely at any test condition over the nitrogen saturation range of 101-136 per cent; that is, bubbles appeared at the bottom of the pipeline under all conditions of air entering.

In order to establish the oxygen nitrogen relationship in supersaturated water with more certainty, air was experimentally introduced into the pipeline intake. With a flow of 2.46 cfs passing through the pipeline, air was metered into the intake at the rate of five, 10 and 15 liters per minute. Five Scholander-type oxygen and nitrogen analyses plus five Winkler determinations were performed at each rate and when no air was entering the line. The air was turned off and the line permitted to clear between each series. The average values expressed in Fig. 5 indicate nitrogen saturation increasing at twice the rate of oxygen increase. Again bubbles appeared at the bottom of the line over the range of 5-15 lpm of air introduced into the pipeline.

Conclusions

The Cultus Lake Trout Hatchery has been investigated as to the cause of periodic outbreaks of gas disease. Air was observed to enter the hatchery pipeline in four different ways resulting in varying degrees of supersaturation with nitrogen depending on the volume of air entering the line. It is suggested that the use of simple Winkler determinations is unsatisfactory as an index of air saturation in closed systems such as pipelines. In the present study, oxygen analyses alone would have indicated only one-half of the excess nitrogen which was present. Dual intake works for hatchery water supplies may be viewed with suspicion. Less than ideal operating conditions may result in unexpected flow patterns.

Acknowledgments

The authors are indebted to Fishery Supervisor F. H. Martin for assistance during the studies at Cultus Lake Hatchery, and to E. Stone for invaluable technical assistance.

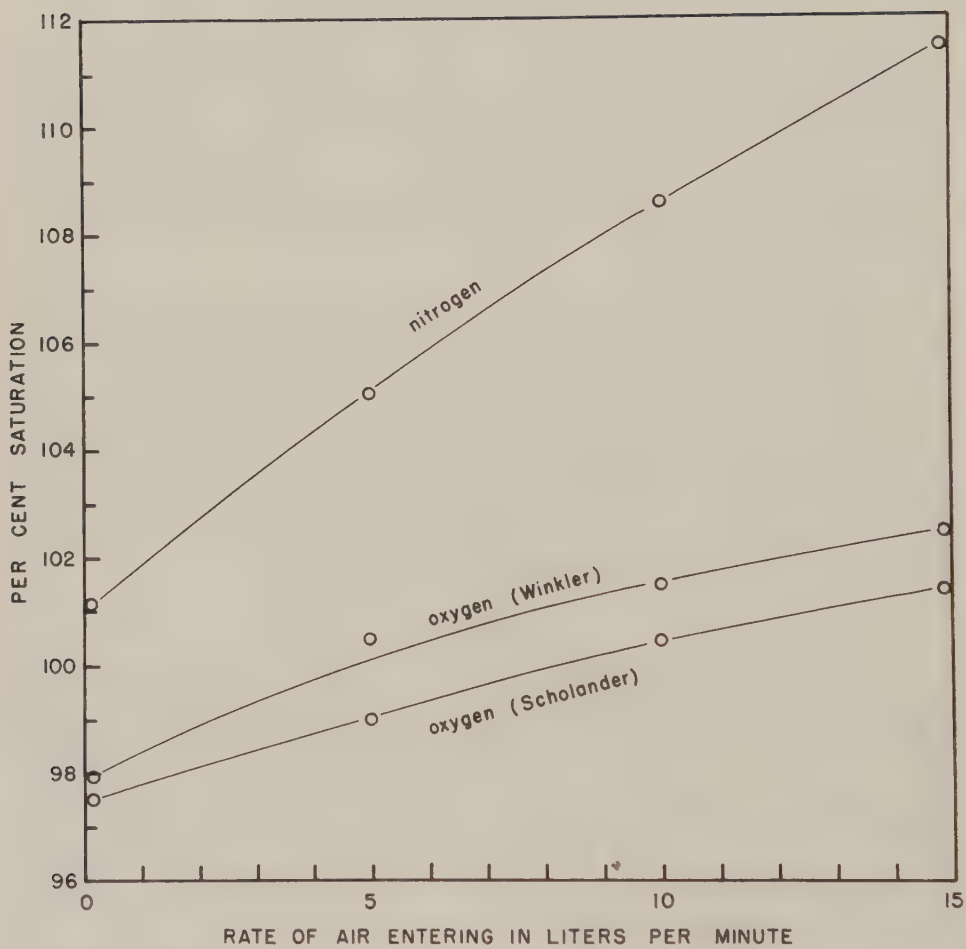


FIGURE 5.—Oxygen and nitrogen saturation resulting from air introduction into hatchery pipeline.

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The Effect of Temperature on the Artificial Culture of Aurora Trout

By

N. D. Patrick

Ontario Department of Lands & Forests, Swastika, Ont.

and

P. Graf

Hill's Lake Provincial Hatchery, Charlton, Ont.

Abstract

Sporadic, unsuccessful attempts have been made to rear aurora trout artificially in Ontario since 1941, and the success of an attempt in 1958 and 1959 is attributed almost entirely to an upward adjustment of the rearing water temperature. All attempts were made at Hill's Lake Provincial Fish Hatchery where the mean daily water temperature seldom reaches 50° F. Increasing this temperature 7° F. for a period of approximately 200 days following fertilization resulted in a much increased rate of growth which was maintained for at least 100 days after the fish were placed in unheated water. At approximately 300 days after fertilization, fish reared in warmed water weighed three times as much as the fish reared in unheated water. Details of culture are included.

Introduction

The aurora trout has been variously described as a separate species (Henn and Rinkenbach 1925), a subspecies of the fontinalis group (Martin 1939), and a colour phase of the speckled trout (Vladykov 1954). The taxonomic status of this fish is open to question at present, and for this reason it is simply referred to in this report as the aurora trout. It is a strikingly coloured char, much sought by anglers who are familiar with it, and for this reason, the Ontario Department of Lands and Forests has made several attempts to rear the fish at the Hill's Lake Provincial Hatchery at Charlton, Ontario.

Aurora trout are known to occur in three lakes in Gamble Township in the Territorial District of Temiskaming, and occupy at least two of these lakes in the company of what appear to be normal speckled trout (*Salvelinus fontinalis*) (Mitchell), as well as possible "hybrids". They spawn late in the fall, just as the lakes are freezing over, and as these lakes are inaccessible by vehicle, the difficulties involving water and air transportation make spawn collection extremely difficult.

All attempts to collect eggs and hatch and rear the fish met with failure prior to an attempt made by the writers in 1958. Records of two previous successful spawn collections are not adequate to explain the failure of hatching and rearing, but it

seems clear that the extremely low temperature of the hatchery water was an important factor. From 11,000 eggs collected in October, 1955, only 10 fish survived until February, 1958, and these ten survivors were finally disposed of at three years of age having reached total lengths of about four inches.

Spawn was successfully collected in the fall of 1958, when a helicopter was made available to transport the eggs from Gamble Township to the hatchery. This stock of aurora trout was used in the investigation reported here and is still thriving at the time of writing (Oct., 1960). They have shown reasonable growth for wild stock, and a planting of these fish made in a virgin lake in September, 1959, reached an average total length of 7.9 inches by September, 1960 (63 specimens).

Collection and Handling of Spawn

Spawn was obtained by capturing wild fish in 1½ inch and two-inch mesh gill nets in late October of 1958 in Whitepine and Whirligig Lakes in Gamble Township. The nets were visited every two or three hours throughout the night, and fish captured were transferred alive to a holding pen located in a small creek flowing into Whitepine Lake. Only four ripe females were captured, one from Whitepine Lake and three from Whirligig, and all of these appeared to be true aurora trout (no red spots). Ten males were also taken and nearly all of these showed one or more small red spots (without halos) below the lateral line on the side of the fish. Milt from two males was used on each lot of eggs taken.

On October 25, 1644 eggs were taken from the single ripe female from Whitepine Lake, and on October 29, a further 2000 eggs were taken from two Whirligig Lake females. In both cases, eggs were taken, fertilized, washed and shipped immediately to the hatchery by helicopter. On the last trip, one ripe male and two unripe females were also taken to the hatchery, but all of these eventually died. On November 2, a total of 1386 eggs were taken from one of the females, but these all died during incubation or shortly after hatching.

Incubation

On arrival at the hatchery, the eggs were measured in fluid ounces and divided into two lots. They were placed in wire baskets suspended in hatchery troughs (one trough for each lot) and the troughs were covered to protect the eggs from light. Water flowed through the troughs (10' long, 10½" wide and 4½" water depth) and over the eggs at 5.5 gallons per minute.

A specially designed heating unit containing a 1000-watt immersion heater was used to raise the temperature of the water in the "warm" trough. This temperature was gradually raised over a period of one week until it was 7° F. warmer than the normal hatchery water. It was maintained at this until the following May 11. The water warming apparatus was so designed that raising the water temperature resulted in a reduced flow so that the water in the "warm" trough flowed at the rate of 1.5 gallons per minute as opposed to 5.5 gallons per minute in the unheated trough. When the warmer was removed on May 11, the original flow was restored.

On November 2, all eggs were hand counted and this count was repeated when they were "eyed" up. The data presented here are the corrected figures based on the hand countings. Daily records were kept of all mortality.

Feeding

As soon as the fry started to swim, feeding was started. This was done by smearing finely ground feed on clay flower pots (2½-inch top diameter) suspended upside down in the water. Three pots were used in each trough and these were cleaned and re-fed three or four times daily. This feeding method permits the fish to take food when they are hungry and has been found to be very effective.

Fry were started on beef spleen, and as they developed, a small amount of beef liver was added. Pork spleen was also added gradually until the diet reached 25 per cent liver and 75 per cent beef and pork spleen. On occasion, a small amount of raw whole egg was mixed with the feed. The normal hatchery water has a small amount of natural food in it which has some effect, particularly when small numbers of fish occupy the troughs.

During the entire rearing operation, the troughs were kept about 50 per cent covered with boards to protect the fish from strong light and undue excitement. These wild fish were noticeably more wary and excitable than the domestic speckled trout reared at the station.

Loss and Weight Records

Each day, the losses of eggs or fish were removed from each trough and counted and recorded. Periodic examination of losses for pathological symptoms was carried out, and when necessary, the fish were treated for the symptoms noted.

Samples of weights were taken as soon as fish were large enough to be handled, and whenever possible, this was done weekly. They were weighed on a 200-gram beam scale when small, and on a 10-kilogram beam scale as they became larger. Each sample to be weighed was "dried" in a fine screen basket and placed in a quantity of water of known weight on the scale. Two different samples of 500 were weighed each time until July, after which the entire lot was weighed and the sample weight of 500 calculated from the total lot weight. Until June, the greatest difference between the two sample weights taken each time was two grams, and after June, the differences increased to a maximum of four grams.

Observations

The eggs incubated in warmed water suffered greater losses (134) than those in unheated water (108) during the incubation period in spite of the fact that the unheated water lot hatched 20 days later. Hatching dates were taken at the time when 50 per cent of the eggs were hatched and this occurred on January 19 and February 8 for heated and unheated lots respectively. Of the eggs taken on November 2 at the hatchery, only 50 hatched and these all died before swimming.

On March 1, the warm water fish were found to be infected with *Chilodon* sp and were treated with formaldehyde. Two days later, a second treatment was carried out. The unheated water fish received the same treatment on April 20 and 22.

Data on weights, losses and water temperatures are presented in Tables 1 and 2, and a graphic demonstration of the difference in growth as evidenced by weight is presented in Fig. 1. Warmed water fish weight records were started on March 16, whereas unheated water fish were not able to withstand handling until April 20.

Temperature records were obtained from the average daily mean temperature recorded at the hatchery, and these daily records were averaged over each interval as shown in Tables 1 and 2. Daily fluctuations in temperature are not great in the normal hatchery water supply, normally one or two degrees and seldom as much as five degrees.

On May 11, some 193 or 197 days after fertilization, (111 days after hatching), the water warmer was required for other work so the warm water auroras were placed in normal hatchery water. This resulted in a reduction in weight gain for some 10 days, but the effect did not last (Point A on Fig. 1).

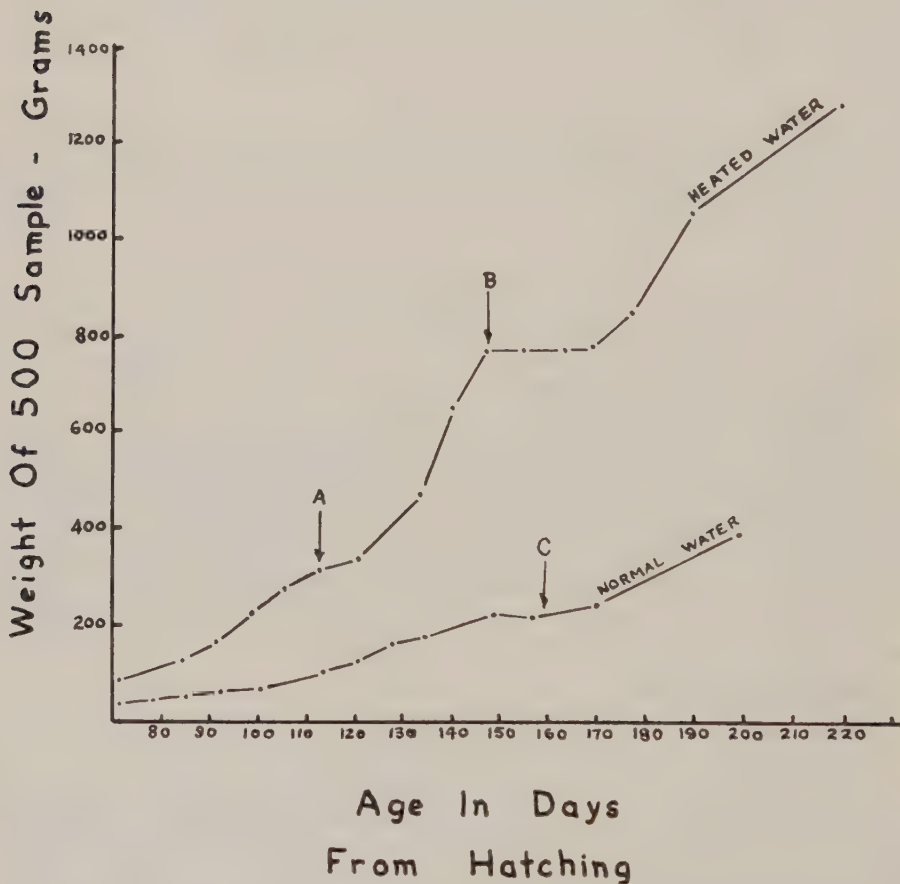


FIGURE 1.—Comparison of Growth of Aurora Trout in Heated and Unheated Hatchery Water.

- Notes (A) Fish incubated and started in warmed water were placed in normal hatchery water.
 (B) Food poisoning occurred following June 15th feeding.
 (C) Reduction in weight gains possibly a delayed result of June 15th food poisoning.

On June 15, the fish were apparently fed spoiled food and an immediate loss in appetite and weight gain occurred accompanied by an increase in mortality. The effect of this is strikingly displayed at Point B, Fig. 1. Normal water fish were fed the

same food, but did not develop the symptoms of food poisoning. The slight dip in the weight curve (Point C, Fig. 1) may possibly be the result of this poisoning delayed in appearing by slower metabolism.

The experiment was terminated on August 26 when a planting was made in a virgin lake. This was done to provide a second more accessible source of breeding stock should the hatchery stock fail to produce. The planting was made of both normal and warm water auroras and one year later (Sept., 1960), a gill net sample of 63 of these planted fish averaged 7.9 inches in total length, and of these, 25 (random sample of the 63) weighed on the average 104 gms. each.

Discussion

Much of the literature available on the effect of various factors on the growth and development of trout refers to domesticated stocks and there are enough examples of differences between "domestic" and "wild" trout to suggest caution in the applica-

Table I. Culture Records for Aurora Trout Reared Initially in Warmed Water

Date	Number of Fish	Temperature			Wt. of 500 Sample in Gms.	Total Loss	Notes
		High	Low	Avg.			
March 16.....	1,788	49	45	47.0	62.5	212	Note (1)
March 30.....	1,768				87.5	232	—
April 13.....	—	49	45	47.5	132.0	—	—
April 20.....	—				165.0	—	—
April 27.....	1,747	52	49	50.0	227.0	253	—
May 4.....	—				280.0	—	—
May 11.....	—	47	40	43.5	315.0	—	Note (2)
May 19.....	—				340.0	—	—
June 1.....	1,736	50	42	45.0	470.0	264	—
June 8.....	—				650.0	—	—
June 15.....	—	50	42	45.0	770.0	—	Note (3)
June 22.....	—				768.0	—	—
July 1.....	1,624	48	42	45.5	765.0	376	—
July 6.....	—				770.0	—	—
July 14.....	—	49	42	45.5	840.0	—	—
July 27.....	1,540				1,050.0	460	—
Aug. 26.....	—				1,270.0	—	—

Note (1) Fish treated for parasite infection (see text).

Note (2) Fish placed in normal unheated water for remainder of experiment.

Note (3) Fish fed spoiled food on June 15th.

Table II Culture Records for Aurora Trout Reared Entirely in Unheated Water

Date	Number of Fish	Temperature			Wt. of 500 Sample in Gms.	Total Loss	Notes
		High	Low	Avg.			
April 13.....	—	—	—	—	—	—	Note (1)
April 20.....	1,511	42	38	40.5	40.0	133	—
April 27.....	1,508				50.0	136	—
May 4.....	—	42	38	40.5	55.0	—	—
May 11.....	—				62.5	—	—
May 19.....	—	47	40	43.5	68.0	—	—
June 1.....	1,505				106.5	139	—
June 8.....	—	50	42	45.0	128.0	—	—
June 15.....	—				165.5	—	—
June 22.....	—				180.0	—	—
July 1.....	—	—	—	—	—	—	—
July 6.....	1,505	48	42	45.5	222.0	139	—
July 14.....	—				220.0	—	Note (2)
July 27.....	1,499				242.0	145	—
Aug. 26.....	1,492	49	42	45.5	400.0	152	—

Note (1) Fish too small and weak to withstand handling involved in weighing and counting prior to April 20th.

Note (2) Fish showed symptoms similar to those exhibited by warm water auroras when food poisoning occurred.

tion of findings from one group to the other. Wild trout in the hatchery differ obviously from domestic trout in their behaviour and continued harsh light or undue excitement probably has a depressing effect on their rate of growth. In this experiment, the fish were protected from both stimuli as much as possible and the growth of the warm water auroras was considered as "fair for wild stock" by the hatchery personnel.

There was considerable variation in the growth displayed by individuals of both lots of fish, so that some (not many) normal water auroras grew as well as the average warm water ones, while others showed little or no growth as far as could be observed.

A "warm water" experiment carried out at the hatchery earlier in 1958 (using spawn from Kamloops trout that had been reared from domestic stock, planted and recaptured three years later) showed results strikingly similar to those obtained from aurora trout. In both cases, fish reared for a relatively short period of their early life in warmed water grew more rapidly than those reared in unheated hatchery water and maintained this increased growth after they were placed back in unheated water.

In the case of the Kamloops trout, adult fish were reared successfully for the first time at the station as a result. It is suggested that this data may demonstrate that a temperature dependent growth threshold exists in these trout which requires their development to a certain stage of "general well being" before they are capable of assimilating ingested food efficiently.

It should be pointed out that in both cases, by the time the water warming apparatus was removed, the normal hatchery water temperature had increased some 5° F. or more (seasonal variation) a situation which only the warm water fish were capable of utilizing.

Acknowledgments

The writers are indebted to the Ontario Department of Lands and Forests and particularly Messrs. G. F. Coyne, District Forester, D. G. Waldriff, Senior Conservation Officer, and C. Hall, Hatchery Manager, for their encouragement and assistance in making facilities available.

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Development of a Fast-growing Strain of Atlantic Salmon (*Salmo salar*)

by

J. A. Dalziel and K. G. Shillington

*Fish Culture Development Branch, Department of Fisheries of Canada, Halifax, N.S.,
and Fish Culture Station, Saint John, N.B.*

In 1943 the Saint John Fish Culture Station of the Department of Fisheries of Canada undertook to develop a strain of fast-growing Atlantic salmon by selective breeding. At the time it was decided by the late James Catt, then Regional Supervisor of Fish Culture for the Maritimes Area, and Mr. K. G. Shillington, Superintendent of the Saint John Fish Culture Station, that this strain should be preserved for five generations to determine if they would lose their tendency to migrate to sea.

The original stock used for this experiment was of late run Miramichi parentage that were hatched in the spring of 1940.

During the years spent in the hatchery, only enough fish were kept in this group at any one time to preserve the strain.

These fish are graded in the fall of the year as fingerlings and are handpicked annually after that so that only the largest fish were used for spawning. About ten per cent of the females in the second generation group spawned as two-year-olds. As a general rule, three-year-old fish were used as spawners. However, at certain times both two- and four-year-old fish were also used.

During the years spent at the hatchery, these fish have been reared in troughs, tanks, long ponds and circular ponds, depending on the availability of space. At all times they were fed on the general hatchery diet and were given as much food as they could consume per feeding without wastage.

The water supply for the hatchery is drawn from the hatchery reservoir and is slightly alkaline. Water temperatures are excellent for rearing fish, never becoming too hot in summer or too cold for any extended period in the winter. Only once between May 1958 and March 1961 did the temperature reach 70° F. and that was for a very short period on one day. The mean summer temperatures run between 60° F. and 65° F. Only December and January are ordinarily considered to be poor growing months. The table on page 58 gives the mean water temperatures and maximum-minimum temperatures for 1960.

As a result of this selective breeding, we now have a strain of fish that will produce approximately 75 per cent smolts as yearlings whereas the normal Miramichi fish reared at the same station produce between 20 and 25 per cent smolts at the same age.

Month	Mean Temperatures F.	Maximum-Minimum Temperatures F.
January.....	35.5	33/37
February.....	34.5	34/35
March.....	34.5	33/36
April.....	41.5	32/51
May.....	53.5	47/60
June.....	61.5	58/66
July.....	64.5	62/69
August.....	67.0	63/70
September.....	62.0	56/68
October.....	52.0	45/60
November.....	42.0	36/48
December.....	37.5	36/39

Comparative lengths and weights of four different strains of Atlantic salmon that were 47 weeks old at the end of March, 1960 is as follows:

Strain	Average Length Ins.	Average Weight Oz.	Approx. No. per pound
Fast growing.....	4.64	0.62	25
Miramichi.....	4.48	0.54	30
River Philip.....	3.12	0.21	76
Rocky Brook.....	3.88	0.36	44

During May 1961, at the yearling stage, the fast growing strain ran about 18 fish to the pound while the normal Miramichi strain at the same establishment ran about 27 fish per pound.

These fish have been distributed in various lakes and streams in New Brunswick. The returns from some of these plantings have been encouraging, especially from Clear Lake, Charlotte County. Angling reports indicated that salmon weighing seven and 13 pounds respectively were taken from this lake during 1960. In Big Salmon River the size of the run has been increased from a low of 200 fish to a high of 1700. One of the reasons for this increase was the stocking of approximately 1300 three-year-old fish the previous year.

Approximately 3000 fourth and fifth generation fish and 5000 sixth generation yearlings have been tagged to date, and even though tag returns have been small, enough information has been gathered to indicate that the tendency to migrate is an inherent characteristic which cannot easily be changed. It is only fair to state here that the small tag returns can, to a large extent, be attributed to a poor type of tag being used rather than a poor type of fish.

Several disadvantages of selection have come to our attention as a result of this experiment:

(1) The egg mortality in this strain of fish is very high when compared with wild stock ova collections of Atlantic salmon reared at the same establishment.

(2) By grading and handpicking only the largest fish, we usually find a high percentage of males in this group.

A means of overcoming or lessening these disadvantages will have to be found.

The advantages of rearing this strain are found in the fact that because approximately 50 per cent more of these fish reach the smolt stage as yearlings than the normal Miramichi fish reared at this establishment, there is a big saving on pond space, labor costs, food and all capital expenses. These larger fish should also be better able to compete with predators in the environment.

The promising results obtained to date from this experiment would seem to indicate that it may be both feasible and economical to rear special strains of Atlantic salmon for brood stock purposes where such traits as early run, fast growing or large fish are desirable.

A Note on the Practical Use of a Salmon Repellent

By

C. R. Forrester

Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C.

Part of the co-operative studies on pink salmon (*Oncorhynchus gorbuscha*) conducted by Canada and the United States in 1959 (in connection with Article VI of the Protocol to the Fraser River Salmon Treaty) called for estimates of the numbers of salmon returning to the spawning rivers. For this purpose some tagging on spawning streams was required. Fish for tagging were usually caught by seine. However, in rivers of moderate size, having clear water conditions, seining of salmon is ordinarily very difficult because the fish are able to escape either under or around the end of the seine before it can be closed. Such was the problem in seining pink salmon in the Klite River, a tributary of the Toba River at the head of Toba Inlet, British Columbia. However, on this river there was a short side channel of less width than the main stream where there would be less difficulty in catching salmon since a seine could be placed right across the channel.

Approximately one-half the length of a heavily weighted 100-foot seine (about two-inch mesh) was strung in such a way as to block the lower end of the channel. The other half of the seine was piled in readiness on the bank for encircling those fish which could be driven downstream into it. With these preparations completed, two men were dispatched to the head of the channel where they commenced "beating" their way downstream. This procedure caused considerable activity on the part of the fish and consequently high optimism on the part of the beaters and spectators. When the beaters had completed their chore, the balance of the seine was quickly run across the channel.

It was clear from the results that most of the fish had evaded capture. A repeat performance produced the same disappointing results. The beaters noted that the majority of the salmon were scattering laterally instead of downstream and were regrouping after the beaters had passed.

After considerable discussion of alternative measures, it was recalled that Brett and McKinnon (1954) had produced "alarm reactions" and a reversal of upstream migration of spring salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) by the use of solutions made from the skin of various mammals, including black bears. Another experiment was set up, using the paws of a bear which had been shot by one of the crew. The arrangements were basically the same as in the original except that the two beaters were each armed with a bear paw. Starting at the top of the run they walked slowly downstream, periodically dipping the paws into the water.

The effects were immediate. The fish became violently agitated and the majority immediately turned and swam downstream. It was a very simple matter to encircle them at the foot of the run and proceed with tagging. In the course of the next few days, the operation was repeated successfully several times; it was concluded that bear paws were an extremely effective repellent to the pink salmon.

The author is indebted to Mr. R. E. Kenny who shot the bear, kindly supplied the paws and assisted in the tagging.

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Book Review

Design of Fishways and Other Fish Facilities. By C. H. Clay, P.Eng. Chief Engineer, Pacific Area, Department of Fisheries of Canada. Available from the Queen's Printer, Ottawa. \$5.00.

Since mankind first began to control inland waters for his convenience there has been some realization of the effects his structures and diversions have had on fish life. Many complete populations of salmon and other migratory fish which he had prized have been wiped out by dams built in the past two hundred years. It was found that even many of the stronger fish such as Atlantic salmon could not surmount falls and dams under certain conditions, and by the end of the 19th Century numerous types and arrangements of aids for fish migration had been devised. Unfortunately, however, there appeared to be little understanding of the requirements and while some devices appeared successful in one installation use elsewhere frequently met with complete failure.

Mr. Clay introduces his subject by outlining how scientists advanced from this early stage. He points out that much still remains to be learned about the basic physiology and behaviour of fish. Extensive programs are underway to acquire increased data on the biological requirements of fish and it is to be expected this knowledge will eventually result in greatly improved fish facilities. At present sufficient knowledge has been accumulated so that fisheries engineers can now design fishways and other facilities for a wide range of situations with a reasonably accurate prediction of efficiency.

Mr. Clay has given us a handbook which will also serve as a textbook to explain fisheries engineering as it stands today. While he refers to some of the more promising innovations now being experimented with, he concentrates on proven facilities and the principles on which present knowledge and experience indicate their operation depends.

The text is well illustrated and lists pertinent references at the end of each chapter. Presentation of each type of facility has been rounded out with a description of its development and a thoughtful comparison of alternative designs, analysing their relative merits for varying conditions. Practical problems of water use, operating efficiency and economics are given full weight. Typical costs are included as a basis for estimates and in one of the appendices, Mr. Clay gives a sample set of contract documents used by the Department of Fisheries in the construction of a fishway at a natural falls on a Pacific coast salmon river.

These documents include structural drawings. However, Mr. Clay does not go into details of structural engineering problems except where fish facilities demand special requirements.

The book's table of contents is appended to this review. The reader will observe that principal emphasis is given to facilities used to pass fish upstream and downstream past obstructions both natural and man made. Besides fishways these include fish locks and elevators, barrier dams and the varied types of fish screens.

An important part of the fisheries engineer's work is to provide equipment and facilities used by biologists to enumerate moving fish and to gauge the effects of ob-

structions or remedial measures. Mr. Clay therefore also gives data on structures developed for these purposes. In addition to fixed installations covered in the chapter on weirs and barrier dams, the specialized floating fish-wheel and inclined-plane trap which have become important supplements to the biologist's more familiar sample-collecting fyke net are described in an appendix. Another appendix summarizes basic hydraulic theory with comments on its application to some of the fisheries engineer's particular problems.

Construction and equipment of hatcheries is beyond the sphere of this book. However, it has been found that artificial spawning channels, duplicating or even improving on the best that nature commonly provides, may frequently fill a need of real importance. Their construction demands careful engineering to ensure they will meet the desired hydraulic and bed-gravel specifications. Mr. Clay has accordingly devoted a chapter to the development and design criteria of this type of facility.

Mr. Clay is Chief Engineer and Chief of Fish Culture, Pacific Area, Canada Department of Fisheries. He was born and reared on Canada's west coast where he obtained his engineering degree from the University of British Columbia. His experience has been intimately linked with the development of fisheries engineering and engineers during the past twenty years in that region. There, North America's valued resource of Pacific salmon has been faced with the conflicting demands of rapid industrialization based largely on the power potential of the salmon rivers, the forests and arable lands which cover their watersheds, and, at an earlier stage, the gold in the river beds.

Persons familiar with fish need not be reminded that these Pacific salmon include several species with widely varying requirements and capabilities. One, the sockeye, is among the most demanding of all fish in the differentiation of innumerable races having highly individualized and specialized requirements for every phase of its fresh-water life. It is not unexpected therefore that Mr. Clay has drawn heavily on this background and given considerable emphasis to the practices developed to satisfy the needs of these Pacific species. At the same time he has travelled widely and studied fisheries engineering practice in many parts of the world. The result is a fine job of extrapolation and comparison with practices elsewhere to produce a text for universal application.

It would be wrong to say fisheries engineering has reached a plateau. It is still an advancing technology, with continuing experimentation and development as our scientists learn more and more about behaviour and needs of the engineer's clients—the fish. This steady progress is undoubtedly a principal reason why a comprehensive text and handbook such as this has not been produced before to satisfy the needs of workers in the field and those who suddenly find themselves thrust in contact with it.

In recent years vast quantities of specialized reports and generalized descriptions of fish facilities have appeared. Fisheries engineers have of necessity accumulated large libraries of such publications in addition to their own notes. This material has been difficult to digest without the leavening of long practical experience in the profession and the guidance of competent experts. "Design of Fishways and Other Fish Facilities" organizes this knowledge. Although development continues, Mr. Clay's book will provide a firm foundation of knowledge for many years not only to fisheries and hydraulic engineers but to the many other people who are concerned with the problems of migrating fish and man's use of their native waters—*B. W. Hamer, Division Engineer, Department of Fisheries of Canada, Ottawa.*

Contents of "Design of Fishways and Other Fish Facilities"

FISHWAYS—GENERAL

Introduction—Some Legal Considerations—Definitions—History.

FISHWAYS AT NATURAL OBSTRUCTIONS

Introduction—The Vertical Slot Baffle—Applications of the Vertical Slot Baffle to Smaller Fishways—Denil Fishways for Natural Obstructions—A Procedure for Installation of Fishways at Natural Obstructions—Defining the Problem—Biological Data—Engineering Surveys and Fieldwork—Design of Fishways for Natural Obstructions—Preliminary—Design of Fishways for Natural Obstructions—Functional—Design of Fishways for Natural Obstructions—Structural Design and Construction—Maintenance and Evaluation of Fishways at Natural Obstructions.

FISHWAYS AT DAMS

Dams and Their Effects on Migratory Fish—Types of Dams—How Dam Operation Can Affect Fishway Design—Preliminary Selection of the Type of Fishway—The Fish Entrance—General—Fish Entrances—Spillways—Fish Entrances—Powerhouse (Powerhouse Collection Systems)—Auxiliary (or Attraction) Water—Fishway Baffles (Including the Special Case of the Denil)—Fishway Capacity—Fishway Exits—Hydraulic Models—Fish Passage During Construction—Fishway Costs.

FISH LOCKS AND FISH ELEVATORS

Definitions and History—Fish Locks—European—Fish Locks—North America—Fish Elevators—Costs of Fish Locks and Fish Elevators.

FENCES (OR WEIRS) AND BARRIER DAMS

Barriers—General—Adult Counting Fences—Selection of the Site—Adult Counting Fences—Detailed Design—Fences for Enumeration of Downstream Migrant Juvenile Fish—Barrier Fences for Adults—Costs of Fences—Barrier Dams—Other Types of Barriers and Fences.

FISH SCREENS

The Need for Fish Screens—Screens—General—Approach Velocity as Determined by Swimming Ability—Mesh Sizes of Screens—The Bypass—Screens for Irrigation Ditches—The Revolving Drum Screen—Screens for Irrigation Ditches—Model "T" and Later Models—Screens for Industrial Intakes—Fixed or Manually Cleaned—Screens for Industrial Intakes—Mechanical or Self-Cleaning—Louwer Diverters—Newer Devices—"Skimmers", "Gulpers", Hanging Cables, etc.

ARTIFICIAL SPAWNING CHANNELS

History of Artificial Spawning Channels—Design of Spawning Channels—General—Design of Spawning Channels—Gravel Size and Grading—Design of Spawning Channels—Channel Cross-Section (Velocity, Depth, and Gradient)—Design of Spawning Channels—Drop Structures—Design of Spawning Channels—Bottom Area and Cost—Operation and Maintenance of Spawning Channels.

SAMPLE OF SOME OF THE CONTRACT DOCUMENTS USED IN THE CONSTRUCTION OF A SMALL FISHWAY AT SPROAT FALLS, BRITISH COLUMBIA

General Conditions—Specifications—Form of Tender—Drawings.

DEVICES FOR CAPTURE OF MIGRATING ADULT AND JUVENILE SALMONIDS

The Fish-Wheel—The Floating, Inclined-Plane Trap.

ELEMENTARY HYDRAULICS

Introduction—Units of Measurement—Definitions—Assumptions—Fundamental Equation of Flow $Q = AV$ —Flow Through Orifices—Flow Over Weirs—Flow in Open Channels—Measurement of Flowing Water—Measurement of Flow in Pipes—Measurement of Flows by Weirs and Orifices—Measurement of Flow in Natural Streams.

